THE RELATION OF CEMENTED CARBIDE TOOLS TO MODERN PRODUCTION.

Paper presented to the Institution, Leicester, Southern, Eastern Counties, Birmingham, Preston and Manchester Sections, by E. W. Field, M.I.P.E., and the late J. H. Garnett, M.I.P.E., A.M.I.Mech.E.

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APPROXIMATELY three years ago, the authors were approached with a view to discussing the new cutting materials known as cemented carbides, which were beginning to attract attention in production circles. As a consequence a paper was prepared and was read before the Birmingham and Sheffield Sections of the Institution, in October, 1932, and March, 1933, respectively, the paper ultimately being published in the June, 1933, issue of the Institution Journal. In this paper the subject was dealt with from an economic point of view, the reason being that at the time, whilst there was evidence of improved cutting performance, the case for cemented carbide had by no means been established and there was much uncertainty with respect to its application.

As first introduced, cemented carbide presented difficulties, inasmuch as its use as a cutting medium involved a totally different technique as compared to previous high speed steel practice. Moreover, cemented carbide was and, indeed still is, much more costly than high speed steel. The authors therefore devoted themselves primarily to determining whether the improved cutting performance justified the difference in cost between high speed steel and cemented carbide.

In addition to this the materials themselves were discussed, the paper concluding with a number of references to existing practice with cemented carbide in the shops of various users.

Having reached certain conclusions in the original paper, which, subsequent experience has fully confirmed, the authors now propose to take a step forward and review the subject in the light of present day experience. Accordingly a knowledge of cemented carbide is taken for granted and is dismissed with the briefest of references. As is generally known, cemented carbide, which is sold under trade names such as Wimet, Ardoloy, Cutanit, and Balfalloy, is produced from a very finely ground metallic flour that is compressed in a die

and then subjected to a sintering process. This is done in a hydrogen atmosphere in two stages, the first hardening the material to a point where it can be worked up into the shapes required for tool bits, which are subsequently attached to the tool shank by brazing. The tool bits are made to the required finished shape, plus a shrinkage allowance of 25%, and in this form are subjected to a second stage of sintering, being received from this in the form known by the user. The complete process results in converting the metallic flour into a metal which is so hard that it cannot be changed in shape and is susceptible only to grinding with specially selected wheels.

In its original form. although capable of cutting metal at remarkably high speeds, cemented carbide was not wholly satisfactory. The material possessed hardness comparable with that of a diamond and could, therefore, be used on metals or substances which would quickly break down the edge of the finest high speed steel. At the same time, the tensile strength of cemented carbide is low and will not stand heavy imposed shear and bending loads to the same extent as will high speed tool steel. This led to a position where cemented carbide was regarded as suitable only for light cutting conditions, that is to say, for operating at a high speed on a light cut and fine feed. Latterly, however, these views have to some extent been disproved. As a result of closer investigation it has been found that by using properly designed machine tools and by otherwise giving effect to the full physical requirements of cemented carbide, much heavier cuts can be taken than were formerly regarded as practicable. In this connection it is interesting to observe that with an originalWidia tool used on cast-iron at a cutting speed of 250 feet per minute the depth of cut was increased from $\frac{1}{4}$ in. to $\frac{1}{2}$ in., and the feed from $\frac{1}{16}$in. to $\frac{1}{8}$ in. per rev., merely as a result of improved technique in its application. These remarks are equally true of other cemented carbides, the whole tendency at present being definitely towards higher speeds, heavier cuts, and coarser feeds.

The earlier cemented carbides, of which Widia now termed Wimet is an example, were largely composed of tungsten into which a cemented matrix of metallic cobalt was introduced. Materials so made were proof against severe abrasive action and were highly successful for machining cast iron, aluminium and non-ferrous metals, as well as numerous non-metallic substances. However, on steel they were not altogether satisfactory, due to the fact that pure tungsten carbide has a high affinity for steel. As a result, when used on mild steel and certain grades of carbon steel, the cuttings are inclined to build up and weld themselves on to the tip. The adhesions constantly break away, causing cavities which are progressively enlarged, the effect continuing until the cutting edge is damaged and must be reconditioned. Alternatively the cutting action is unsatisfactory and the tool will ultimately fail. To

obviate this defect a recent tendency has been to introduce alloying elements such as molybdenum, tantalum and titanium into the cemented carbide. The reason for this is that molybdenum, tantalum and titanium have a low affinity for steel and very effectively eliminate the tendency for cuttings to build up when machining steel. It is in materials embodying these elements that the greatest progress has been made during the past three years, and the machining of steel with cemented carbide is now almost as commonplace as cast iron and other metals. One outstanding feature of steel machined with these later cemented carbides is the remarkably fine finish which is obtained. Such high finish is not obtainable with ordinary tungsten carbide and the only theory that the authors can advance on the point is that carbides embodying low steel affinity alloys, are smoother—they have a greasy feel when handled—and cut freely without ragging. The result is a smoother finish which remains bright and free from oxidation for prolonged periods. This is one of the peculiarities of steel machined with such carbide and is believed to be due to the fact that the smooth surface prevents the entry of coolant, the latter being the cause of oxidation and tarnishing. A contrary opinion on the reason for smooth finish is that molybdenum-titanium-tantalum carbides are softer than the harder grades of tungsten carbides—the specific gravity is certainly less—and whereas tungsten carbide will crumble slightly and cause surface roughness, molybdenum-titanium-tantalum carbide will burr over and exercise a burnishing effect on the work surface.

The finish obtained on cast iron with cemented carbide is much better than can be obtained with any high speed steed, close grained iron having an extremely clean appearance. On steel the finish seems to improve as the Brinell hardness gets higher and a much better finish is obtained on steel with a nickel content than on straight carbon steel, although the latter has a finish which can be termed quite good.

Cemented Carbide and High Speed Tool Casts Compared.

In the previous paper a series of charts were introduced in which the cost of tooling with cemented carbide under correct conditions was compared with high speed steel. The charts dealt with a variety of different examples selected from actual practice and showed that in the majority of cases the use of cemented carbide was economically justified even to the extent of replacing machine tools with others more suitable for its application. In the past there has been much confusion of thought with regard to the purchase of new productive machinery simply to meet the requirements of cemented carbide. That in many cases new machine tools are desirable if not altogether necessary in order to obtain the best results, is a fact that cannot

be denied. Machine tool makers have devoted considerable attention to the subject and have designed and marketed improved machines capable of using cemented carbide to its maximum advantage. At this juncture a comparative analysis of such machines should prove of interest.

Let us take the instance of a machine tool, with its equipment, now ten years old, and therefore built before the era of cemented carbide tools. This installation cost when new £500, and when depreciated at the rate of 10% per annum is now valued at about £185. This machine is countinuously producing one component every thirty minutes of the working day.

On a modern machine using cemented carbide to reasonable advantage one component can be produced every fifteen minutes of the working day. The cost of the new machine and equipment is £700.

To enable a reasonable comparison to be made we will assume that the old machine has a further ten years of productive life and that the new machine should be expected to recover its capital cost in five years. The operator on the old machine has an inclusive rate of 1s. 6d. per hour, but on the new machine it is reasonable to pay a little more because of the increased output the operator is able to give and the rate is, therefore, taken at 1s. 8d. per hour. Overheads on labour costs are taken at 150% and 160% respectively, the later figure—for the new machine—covering such items as increased power consumption and increased inspection charges, due to the higher rate of production.

The figures resulting from this comparison are given in Fig. 1. From this it will be observed that although the depreciation figure per piece on the new machine is three and three-quarter times that of the old machine, the cost per piece shows a 6¾d. saving.

To enable us to arrive at a figure which will give a better indication of the advisability of giving serious consideration to the installation of modern machinery we will examine a chart based on the production of a week of forty-five hours, taking the sales price of the component at 4s. out of which the material costs 1s. 6d. Fig. 2 gives the figures in relation to this comparison.

No doubt the question will emerge as to how far comparisons of this kind can be taken. The illustration given in Fig. 1 is by no means out of the ordinary, indeed, so true is it that Fig. 3 gives a graph indicating the position relative to the replacement of any machine, providing the new machine can save either one third or one half of the production time. In this illustration the vertical scale indicates the cost per piece, including operator's wages, depreciation and overheads, but excluding materials and profit. The horizontal scale gives the prices of existing machines and new machines at four

FIG. 1.

COST COMPARISON BETWEEN EXISTING AND NEW MACHINE.

Value of existing machine and tools			£185	0	0	Value of new machine and equipment			£700	0	0
Production time			30 minutes			Production time			15 minutes		
Machine depreciation life			10 years			Machine depreciation life			5 years		
Operator's wages			1/6 per hour			Operator's wages			1/8 per hour		
Works overheads			150%			Works overheads			160%		
			£	s.	d.				£	s.	d.
30 minutes at 1/6 per hour			0	0	9	15 minutes at 1/8 per hour			0	0	5
Depreciation of machine per piece = £185 / 10 years of 50 weeks of 45 hours = 2d. per hour.						Depreciation of machine per piece = £700 / 5 years of 50 weeks of 45 hours = approx. 1/3 per hour.					
∴ 30/60 of 2d.			0	0	1	... 15/60 of 1/3...			0	0	$3\frac{3}{4}$
Overheads 150% on labour			0	1	$1\frac{1}{2}$	Overheads 160% on labour			0	0	8
Cost per piece			0	1	$1\frac{1}{2}$	Cost per piece			0	1	$4\frac{3}{4}$

FIG. 2.

COMPARISON.

OLD MACHINE.		NEW MACHINE.	
Production per 45 hours=	90 pieces	Production per 45 hours=	180 pieces
Cost per piece	0 1 11½	Cost per piece	0 1 4¾
Cost of material per piece	0 1 6	Cost of material per piece	0 1 6
Profit per piece	0 0 6½	Profit per piece	0 1 1¼
Selling price	0 4 0	Selling price	0 4 0

	£ s. d.
Profit on 180 pieces at 1/1¼... ...	9 18 9
Profit on 90 pieces at 6½d.	2 8 9
Increase of profit per week	7 10 0

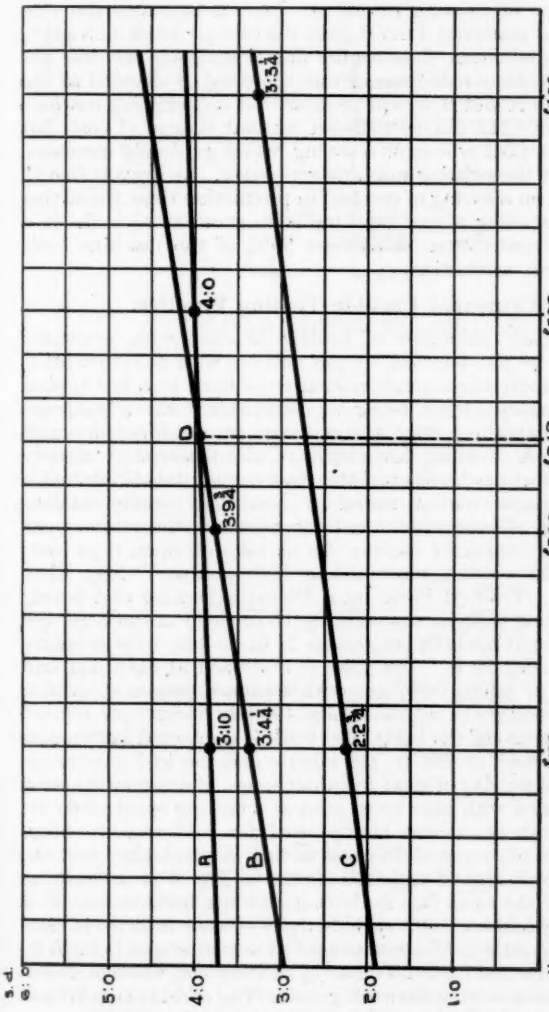


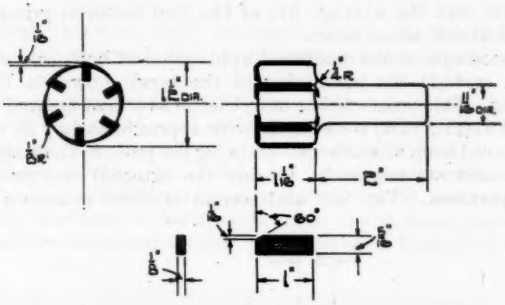
Fig. 3.

Line A shows the cost per piece on a tenyear-old-machine including labour, depreciation, and overheads. Line B shows the cost of the same piece on a new machine (priced at four times the value of the existing machine), assuming that the new machine will reduce the floor to floor time by one third. Line C shows the cost on a new machine, assuming that the time can be reduced by one half.

times the price of existing machines. Line A indicates the cost per piece on old machines. Line B gives the cost per piece on a 33⅓% reduction in production time, whilst line C indicates the cost per piece on a 50% time reduction. From the point D situated at the crossing of lines A and B, it will be clear that any existing machine with a value of £242 can be replaced without change of cost, but anything below £242 will show a saving, which gradually increases, as the value of the existing machine gets lower. As regards line C, which is based on a saving of one half in production time, the saving effected by installing a new machine is so great as to make it a worth-while consideration on at least 90% of the machine tools tused in modern production.

Examples of Cemented Carbide Tooling Practice.

Although many examples of tooling practice with cemented carbide could be put forward, as the authors wish to review other aspects of its application, consideration is confined to a few typical cases, the primary object being to demonstrate the advantages which can be obtained from the material on machines designed for its use. A working knowledge of the material is already possessed by most machinists and abundant cutting data is obtainable from the catalogue matter issued by cemented carbide makers. As an example of intermittent cutting, which is one of the most severe tests for cemented carbide, let us take an open type cast-iron motor yoke which is machined by Metropolitan-Vickers Electrical Co. Ltd., Trafford Park, on a Richards turning and boring mill. The casting is 26 in. diameter by 18 in. deep in the bore, the latter having eight lands or projections 2½ in. to 3 in. wide at centre distances of about 10 in. The yoke is machined at each end and bored to plus or minus 0.002 in., with standard cemented carbide boring and facing tools, which receive 190 percussions per minute due to the presence of the lands. The work is completed in two cuts at a cutting speed of 160 ft. per minute and the tool only needs regrinding once per day of eight and a half hours. Previously the same job was machined with high speed steel at a cutting speed of 60 ft. per minute, with an almost hourly need for tool reconditioning. As an example of long tool life and saving in machining cost the cemented carbide tipped end mill shown in Fig. 4 is interesting. This is used by the same firm for boring cast iron meter cases. It is 1½ in. diameter and has eight carbide tips which are inserted in slots and brazed in position. The tool is used at a cutting speed of 320 ft. per minute and is fed by hand on a $^{3}/_{32}$ in. deep cut, the tool averaging ninety hours cutting between grinds. The carbide tips Wimet N, and on a run of 25,000 cases the saving in production cost compared to high speed steel practice worked out at approximately £200.



END MILLING CUTTER. WITH WIMET TIPS.

Fig. 4.

Applied to automatic screw machines cemented carbide shows to advantage, not so much as a result of higher cutting speeds, but as a result of long tool life. As an example take the brass spindle shown in Fig. 5. This is produced on a Petermann Automatic at a spindle speed of 6,000 r.p.m., with the tools feeding at 0.005 in. per revolution. The output is 140 spndles per hour and the tools only require grinding

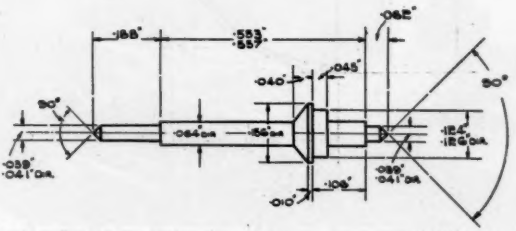


Fig. 5.

once per eight and a half hour day. High speed steel tools used for the same piece do not give the same high finish and require grinding at least three times per day.

On a No. 2A Ward Capstan Lathe, $\frac{3}{8}$ in. and $^{7}/_{16}$ in. diameter by $2\frac{1}{2}$ in. long rivets are being produced from $\frac{1}{2}$ in. and $^{9}/_{16}$ in. diameter black nickel steel bar in one cut using a Cutanit tipped tool. The rivets are held to plus or minus 0.0005 in. on the outside diameter and have a highly polished surface. This result is obtained direct from the tool which operates at a cutting speed of 235 ft. per minute on a feed of 0.0035 in. per revolution. The depth of cut

is 0.062 in. and the average life of the tool between grinds is 360 pieces, or about seven hours.

As an example of the combined application of both tungsten and tantalum carbide the machining of the bowl shown in Fig. 6 is interesting. This comes to the turret lathe as a heat treated roughly machined forging of 60 tons tensile with approximately $\frac{1}{4}$ in. of metal to be removed from all surfaces. To bring the piece to the stage shown four processes are required; two on the external and two on the internal portions. The first and second of these processes are for

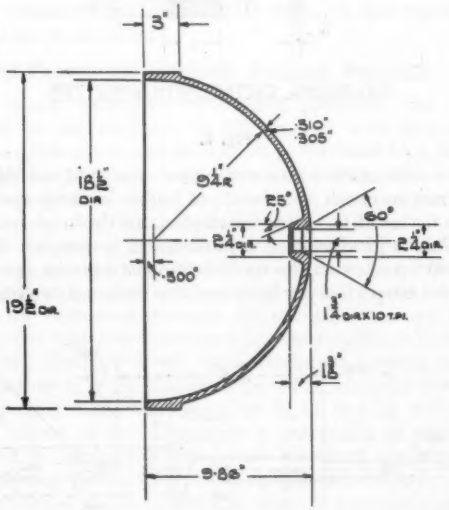


Fig. 6.

metal removal purposes, and about $^1/_{16}$ in. is left on all over for the two final processes. The relative thinness of the wall will be noted from the sketch; also the fact that the thickness of the radial portion is held to a tolerance of 0.005 in.

The layout for dealing with the first and third processes is shown in Fig. 7. Although the turret carrying the boring bars is not shown, the boring bar equipment is of orthodox design and does not call for particular comment. The operations under review consist of generating the external radius. For this purpose two tool blocks are mounted on a radial slide and are spaced in such a manner that one commences to cut in the small bore, the other being in alignment for commencing to cut on the largest radial diameter. It will be

appreciated therefore that the total length of the slide travel is only a little over one half of the surface distance of the external radius.

For the roughing cuts a trial was made during tests between a really good high speed steel and tungsten carbide. The high speed steel tools allowed the use of a cutting speed varying between 35 and 60 ft. per minute. When replaced by tungsten carbide tools the speed was successfully increased to 150 to 180 ft. per minute, the feed being constant in both cases. For the finishing cuts on the same surfaces tantalum carbide tools are used instead of tungsten

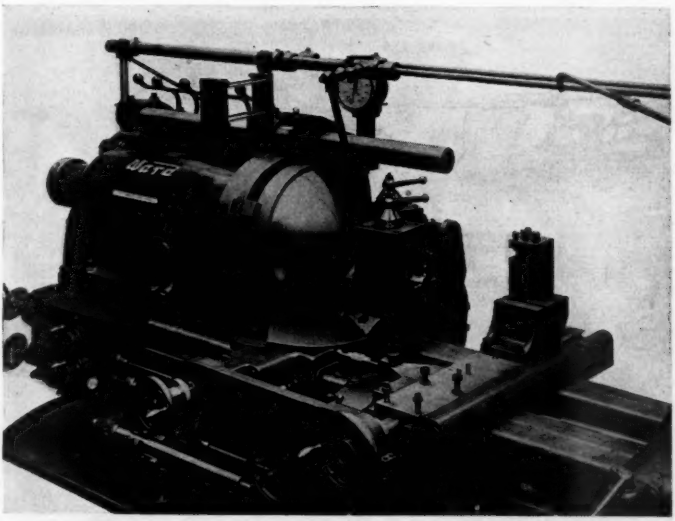


Fig. 7.

carbide, the cutting speed being increased to 230 to 270 ft. per minute and results in a particularly clean cut and highly finished surface. The feed was approximately one half that used for the roughing cut.

The second and fourth processes consist of machining the internal portions and the tool layout is given in Fig. 8. So far as consideration need be given in this paper to the example it is the radial generating cuts to which attention is directed, the arrangement being indicative of an attempt to secure maximum economy by maintaining practically a constant cutting speed on a diminishing diameter. For facing operations this is particularly important, as otherwise the material is not used to the best advantage. As illustrated the bowl

is developed by a special swivelling toolholder mounted on the hexagon turret, the main castings of the holder being given support by the overhead pilot bar. Two tools are in action simultaneously, the swivelling movement being obtained through a rack (carried in the toolholder) which meshes with a spur gear on the rotating portion, movement of the rack being obtained by the automatic surfacing action of the lathe cross slide. The roughing cuts are taken by tungsten carbide tools using cutting speeds similar to those mentioned in connection with the first and third processes. For the finishing cut, however, only one tool is employed over the whole

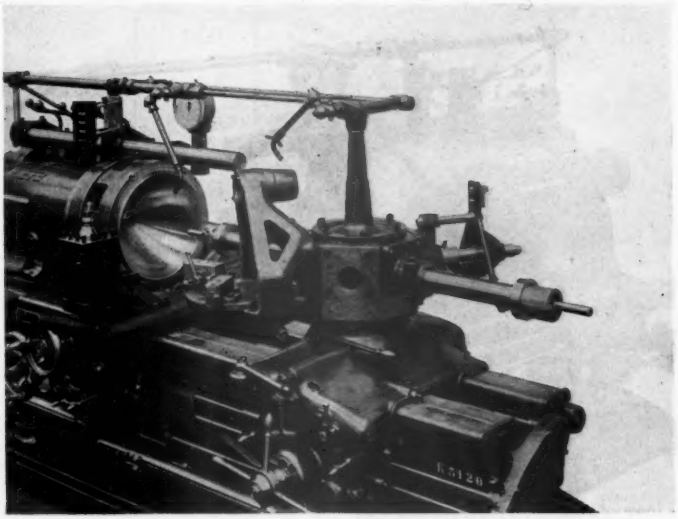


Fig. 8.

surface, the finish obtained, which is not done justice by the photograph, leaving one with the impression that a long and very effective polishing process and not a turning cut had been employed.

To maintain a uniform cutting speed over the radial surface a variable speed commutator motor was used in combination with a tachometer driven from the spindle. The lathe headstock itself, although of the single pulley type and giving a very wide range of speeds, was insufficient to meet the requirements as the speed variations were too far apart to give uniform variations in circumferential speed over a radial surface. The changes would have

been too marked and would result in a different appearance at portions of the turned surface. To obviate this the variable speed motor was introduced, its speed being gradually accelerated as the tool traversed towards the centre. In other words the circumferential speed of the work was maintained to suit the diametral position of the tool. To accomplish this the tachometer, which is belt-driven by the spindle, is set at eye level, and acts as a rev.-counter, the operator watching the tachometer and accelerating its speed in accordance of the radial position of the tool, accelaration being effected in accordance with a series of marks on the tool holder or slide. In operation the motor is started, and in the present

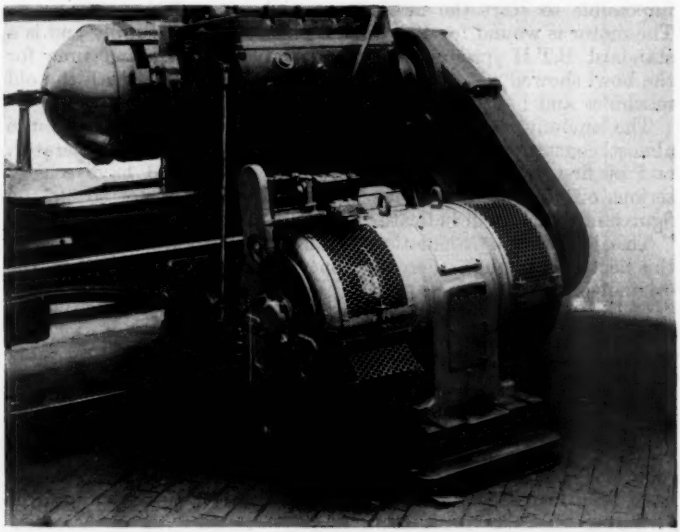


Fig. 9.

instance runs at its lowest speed of 300 r.p.m. A suitable spindle speed is then selected which will give the required circumferential speed on the largest work diameter, the speed of the motor then being increased (as the tool moves round the radius) by push buttons in front of the headstock. These act on a small pilot motor which swings the brush gear of the commutator motor, increasing the motor speed until it is actually running at 1,500 r.p.m. by the time the cut is completed. The internal cut on the component starts at 18½ in. diameter and finishes at about 3½ in. diameter, the

circumferential speed being held reasonably constant over the whole length of cut as a result of the above mechanism. Compared with a straight single speed motor the electrically driven installation just described is, of course, comparatively costly but is justified by the results and could be made even more effective by adding a mechanical coupling and taking motion from the lathe cross-slide, thereby actuating the pilot motor direct instead of through the tachometer and push buttons.

The arrangement actually employed is shown in Fig. 9. The pilot motor which increases and decreases the speed of the main motor is seen on top of the motor. When this is stopped the brush gear automatically returns to the low speed position so that it is impossible to start the motor at a higher speed than 300 r.p.m. The motor is wound for 400 volts, 3 phase, 50 cycle supply and is a standard B.T.H. production. The complete production time for the bowl showed a saving of nearly 75% as compared with the old machines and high speed steel tools previously used.

The amount of cuttings produced on this job necessitates the almost constant attention of a labourer as well as the operator, and at first sight it might appear that this would have a very serious effect upon the saving effected, but this is not so, as the figures in Fig. 10 will indicate.

This is a similar calculation to that shown in the early part of this lecture although there are one or two modifications to the original example.

For instance in this example it has been assumed that the old machines had actually no book value and that the labour cost on the new machine is twice that of the old. Actually the same operator was transferred to the new machine, but as mentioned above, it was necessary to add a labourer to the installation, this increasing the labour cost per hour, directly chargeable to the job, to 2s. 6d. The amount of power required for the heavy metal removed at high speed is rather above the average, so overheads have been increased to 200% so that there can be no question of favouring the new installation unduly. Despite these increases, however, the new machine shows a cost saving of almost £1 per unit.

The subject of intermittent cutting is one which needs some consideration as there seems to be a very general idea that cemented carbides are unsuitable for machining broken surfaces. This is obviously an idea caused by an attempt to use tipped tools on an unsuitable machine, lacking in rigidity. The key note for the successful use of any of the cemented carbide group materials must be the elimination of spring, or, in other words, rigidity of both machine and tool are of vital importance.

It is really through the use of unsuitable machines that the

FIG. 10.

COST COMPARISON ON INSTALLATION OF NEW TURRET LATHE.

OLD MACHINE.		NEW MACHINE.	
Value of machine and equipment ...	Nil.	Value of machine and equipment ...	£1250 0 0
Production time	25 hours	Production time	6 hours
Machine depreciation life	Nil.	Machine depreciation life	5 years
Operator's wages	1/3 per hour	Operator's and labourer's wages ...	1/6+1/- per hour
Works overheads	150%	Works overheads	200%
	£ s. d.		£ s. d.
25 hours at 1/3 per hour	1 11 3	6 hours at 2/6 per hour	0 15 0
Depreciation	Nil.	Depreciation of machine per hour. £1250 / (5 years of 50 weeks of 45 hours) =26.6d. per hour.	
		Depreciation per piece	0 13 4
Overheads 150% on labour	2 6 10½	Overheads 200% on labour	1 10 0
Cost per piece	£3 18 1½	Cost per piece	£2 18 4

materials under review are generally thought to be only suitable for fine feeds. This fallacy is disproved by nearly every machine designed to utilise tungsten carbide to advantage and examination of most of these machines will show that not only are higher speeds available but the feed range is at least equal, if not greater, than on old type machines.

It all resolves itself into the elimination of clearances in the fitting of the machine. You will have noticed that practically all lathes—whatever their type—are now fitted with pre-loaded ball and roller bearings to the spindles, and that saddles are more massive and tool sections heavier. An example of intermittent cutting on a boring

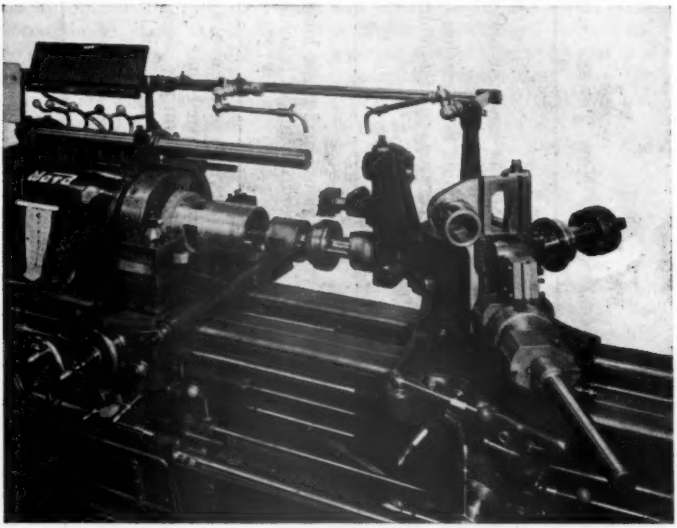


Fig. 11.

mill has already been mentioned and another example, this time of turret lathe practice, will be of interest.

Fig. 11 shows a modern layout for machining a locomotive piston valve liner in which the valve ports are cast, thus involving intermittent cutting on both the external diameter and in the bore. As the turning and boring are effected simultaneously and both roughing cuts are almost $\frac{1}{4}$ in. deep it will be realised that the successful production of this job proves without doubt that intermittent cutting on cast iron need not be feared providing the rigidity of the machine and tools is as it should be.

The layout is interesting from the point of view that four tools are used simultaneously on the roughing cuts. The special boring bar shown in alignment with the component carries two cutters, the rear one being permanently set to size whilst the front one is carried in a swivelling block actuated by hand through a suitable cam and pusher bar.

The object of this is to enable the turret to be advanced until the leading cutter is half way up the bore at which position it is opened out to size and the automatic traverse engaged. By this means, although the bore is of one diameter right through it is only necessary for the turret to traverse half the length of the casting to completely machine it. The external portion has two dimensions, the step being approximately at the half distance, so

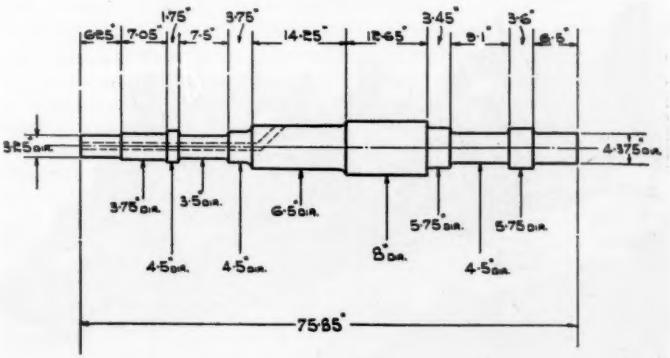


Fig. 12.

that the cutter in the knee toolholder will turn the smaller diameter whilst a tool in the square turret on the cross slide attends to the diameter nearer the chuck.

This roughing operation is effected at approximately 150 ft. per minute with a feed of 44 revolutions per inch. A casting 10 in. in diameter with an 8 in. bore, 15 in. long, is roughed out in eight minutes. The finishing cuts are also taken simultaneously although in this case the turret takes the full length of traverse. Centre line pilot bars, coupled with overhead pilot supports and the addition of roller pilots in the bore being machined, point out the importance of securing the most adequate support during cut. Experience has shown that 20 liners are machined on an average without tool reconditioning. The final operation on the layout consists of cutting off the finished liner from the riser which is used as a chucking piece.

On the subject of metal removal it is rather difficult to give figures because there are so many variables to be taken into consideration, but on some of the latest lathes with ball and roller bearings to the spindle and rigid saddles some extraordinary figures are obtainable.

For instance the armature shaft shown in Fig. 12 is made from steel of 40 tons tensile strength on a Lang shaft roughing lathe (Fig. 13). Four tantalum carbide tipped tools are in action simultaneously at an average cutting speed of 270 ft. per minute with a

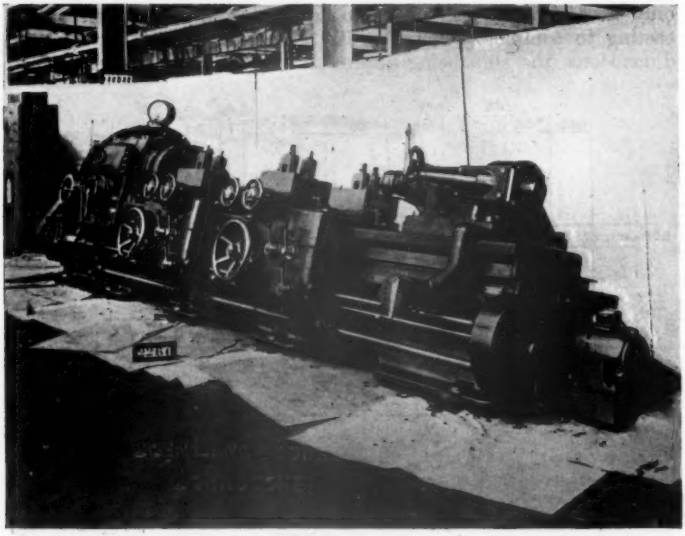


Fig. 13.

feed of 0.030 in. per revolution. The depth of cut on each tool is $\frac{1}{2}$ in., and the metal removed is approximately 200 cub. in. per minute. The horse power used on these cuts is in the region of 100.

Incidentally the best cutting speed which can be used under similar conditions with high speed steel is 60 ft. per minute.

Figures secured from several sources by the use of various machine tools indicate that 2 cub. in. per h.p. minute is a reasonably good metal removal performance on steel up to 40 tons tensile whilst on cast iron of 180 Brinell 4 cub. in. per h.p. minute can be attained without much difficulty.

These figures however presuppose that metal removal is the only consideration but production times cannot yet be deduced by the amount of metal to be removed from a casting or forging.

It would, of course, be possible to go on almost indefinitely with examples of modern practice, but time will not permit. Before leaving the subject of combination cutting, however, let it be said that many layouts take advantage of the various diameters on a component to utilise high speed steel for the small bores with tungsten carbide for the larger diameters, thus combining cuts at something approaching efficient cutting speeds for both types of material. This is an excellent plan because in the majority of instances, it is possible to utilise standard types of cemented carbide tools leaving the more complicated tools of smaller section to be made in high speed steel at a much lower cost than they could be produced with cemented carbide tips.

Quite apart from the high-speed cutting capabilities of cemented carbide materials their edge holding characteristics shows a very definite economy on a wide range of other work. A typical instance is that of a Cutanit tipped tool used for the finish turning cut on a batch of machine tool spindles. These are 40 in. long and have several stepped diameters varying from 3½ in. to 4 in. with a 7½ in. diameter flange at one end. The average cutting speed for the finishing cut is 440 ft. per minute, the depth of cut being 0.01 in. and the feed 44 cuts per inch, or 0.023 in. per revolution. The material is 0.5 carbon steel with a Brinell hardness of 207. Seventy spindles are regularly machined before the tool needs re-grinding, representing a total tool travel of 230 ft. When using high-speed steel at a cutting speed of 120 ft. per minute not more than six to eight spindles can be machined before the tool needs reconditioning.

Observation of a Wimet tipped tool taking a ⅛ in. deep cut on centrifugal cast-iron bushes is equally interesting. Using a cutting speed of 180 ft. per minute and a feed of 0.01 in. per revolution the tool actually ran for over four weeks, during which period it did over 110 hours cutting, and did not then require regrinding. In this case the tool was used in combination with a high-speed steel boring tool which could not be applied at a greater cutting speed than 50 ft. per minute, thus restricting the cutting speed on the external diameter, the carbide tool otherwise being capable of operating at a substantially higher cutting speed. Relative to this example it should be noted that despite the low cutting speed the high speed steel tool required reconditioning at least once per day.

As applied to operations such as planing and milling, cemented carbide shows to great advantage and has proved a particularly important asset to the machine tool maker, in that it permits the use of much harder cast-irons than formerly for bed and slide

members. At the works of the Butler Machine Tool Co. Ltd., Halifax, cutting speeds of 160 to 180 ft. per minute, with a return traverse of 220 to 240 ft. per minute are in regular use on cast-iron, using Ardoloy, removing $\frac{1}{2}$ in. to $\frac{5}{8}$ in. of metal at a feed of $\frac{1}{32}$ in. without difficulty. This applies to intermittent cutting and full speed entry cuts, very few breakages being experienced with either round nose or knife edge tools used under such conditions. In this case it is estimated that a 20% saving in time is effected despite the fact that the cemented carbide tools are used at only half the feed of high-speed steel tools.

Applied to milling the use of cemented carbide is more or less confined to facing operations. This is due to the fact that no satisfactory method has yet been evolved for making cemented carbide blades suitable for spiral milling cutters or of securing them in the cutter body. However, by adapting one's milling practice to suit facing cuts, which is a noticeable tendency at the present moment, highly successful results are obtained. On motor car cylinder blocks Wimet tipped inserted blade milling cutters are being used for taking 0.01 in. deep finishing cuts at a cutting speed of 125 ft. per minute on a feed of 12 in. per minute, the cutters machining 1,500 blocks between grinds.

For boring operations the development of cemented carbide has proved particularly important and many motor-car cylinders are being finish-bored with this medium in preference to grinding or honing. The operation is commonly referred to as fine boring, the claim being that bores sized by this method possess better lubricating properties, the single point tool leaving a uniform microscopic thread in which a supply of oil is retained. Also the tool is applied in such a manner that it does not exert pressure on the walls of the bore like a honing tool, and is less liable to cause distortion. On cast-iron cylinder blocks established practice is to leave 0.016 to 0.018 in. in the bore and to remove this with a cemented carbide broad faced tool which operates at a cutting speed of 318 feet per minute on a feed of 0.0015 in. per revolution. The bores are readily sized to within 0.0002 in. and the tool machines from 25 to 40 bores without regrinding.

A recent development consists of size boring, steel aero-engine cylinders by the same method. In this case the entire cylinder and boring tool are immersed in a tank of coolant and the spring type cemented carbide tipped single point boring tool is applied at a cutting speed of 600 to 700 ft. per minute, taking a 0.01 to 0.012 in. deep cut at a feed of 0.004 in. per revolution. Cylinders with a $6\frac{1}{16}$ in. diameter by $10\frac{1}{2}$ in. long bore are sized in ten minutes and are accurate to within 0.0008 in.

Chip Control.

Prominent questions which are raised as a result of the development of cemented carbide include the effect on manufacturing practice ; on machine tool design and the control and disposal of cuttings resulting from the high cutting speeds which the material is capable of maintaining. To consider each of these items briefly it will be appreciated that so far as cuttings are concerned and particularly steel cuttings, some measure of control is a vital necessity. On cast-iron and non-ferrous metals in general, control is not difficult, sheet steel chip guards readily keeping the cuttings within the confines of the machine. However, when cutting steel, especially on the lathe, the problem is quite different. The depth

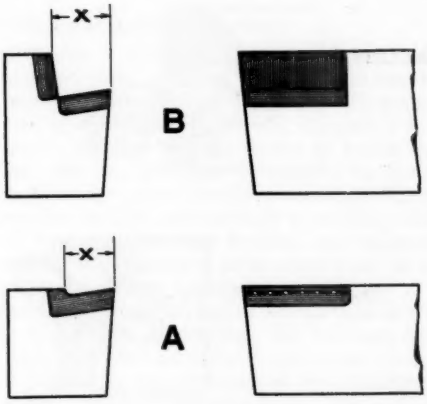


Fig. 14.

of cut and feed of the tool have an important bearing on the problem; as do also the rake and clearance angles on the tool top albeit it is the speed of cutting which presents the greatest trouble. There are two particularly dangerous types of chip ; first the chip of nearly square section which breaks and flies in all conceivable (and quite a few inconceivable) directions. Chip guards of adequate strength, however, can be used to overcome this. The second type presents far more actual danger to the operator and is presented by the ribbon of metal produced by a fairly deep cut resulting from a fine feed and a very high cutting speed. The ribbon thus produced is made at the same rate per minute as the circumferential speed of the work, that is to say, if the cutting speed is 650 ft. per minute, the ribbon swarf is produced at the rate of 650 ft. per minute,

which is equal to more than 7 m.p.h. Chips such as this, if left uncontrolled, are a very definite danger not only to the operator but to others in the vicinity of the actual machine. Many attempts have been made to prevent formation of this ribbon chip whilst still maintaining the same speed and feed but not with entire success.

Providing a machine is on repetition work there are two methods which can be tried and are similar in type. The first consists of grinding a chip rolling groove in the tungsten carbide tip as shown at A in Fig. 14. The second involves the use of a specially made tool as shown by B. By trial and error ribbon chip from certain materials can be rolled up into tight little curls which readily break

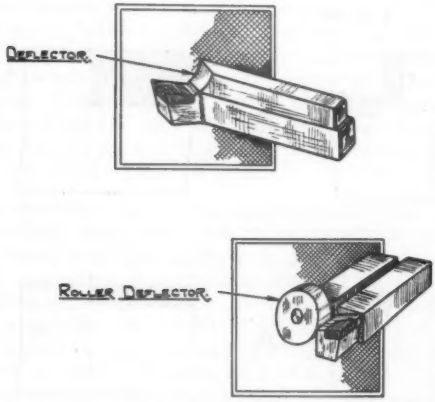


Fig. 15.

off. The trial and error method involved is to get the second edge, marked X on the drawing, into a definite position in relation to the actual metal removing edge, and is not quite so easy as it sounds owing to the lack of homogenity in most commercial types of steel, and the wide variation in the speed-feed range of different makes of machines. A third method and one to be recommended on machines called upon to handle a variety of work is shown in Fig. 15. This method involves the use of a steep, angled deflector placed along the top of the tool. The deflector can be made of 18% high-speed steel properly heat treated. It can also comprise a carbon steel shank with a cemented carbide or Stellite facing, the latter being probably the more economical. The deflector is effective under very heavy duty conditions, and can be adjusted in its relation to the cutting edge with comparative ease.

Experiments have been made with a high-speed steel roller mounted in a similar manner to that shown at B, but up to the present the solid deflector has proved the most effective. Quite recently the authors have used a chip breaker of this type at cutting speeds, up to 4,000 ft. per minute with quite good results although at speeds such as this efficient surrounding guards are essential in addition to the chip breaker. Incidentally this research cutting is very interesting although far and away above the realms of practical production at the present moment. However, it may be mentioned that at such high speeds a tool life of two minutes is obtainable with a cut 0.01 in. deep and a feed of 0.008 in. per revolution with at least two cemented carbides at present on the market.

Effect on Manufacturing Practice.

The development of cemented carbide tools has had a pronounced effect on manufacturing practice, but for time reasons the subject can only briefly be exploited in this paper. In many cases revised procedure has proved desirable if not altogether necessary. This is mainly due to the high cutting speeds at which the tools can be used, and also the requirements of rigidity in the work and tool which the satisfactory use of the alloy demands. In some cases it is mainly a question of different methods of tooling, and in others the provision of better facilities for loading and supporting the work. Loading facilities also influence lathe work due to the short time cycle when cutting at high speeds.

An outstanding feature of cemented carbide is the fine natural finish which is obtained direct from the tool and consequent upon which the necessity for subsequent processes such as reaming, grinding, or lapping is greatly reduced and sometimes eliminated. The combination of high cutting speeds and fine feeds also encourages the use of single-point tools. This tendency is further emphasised by the ability of cemented carbide to resist abrasive action when used on castings or forgings and provides definite manufacturing advantages. In the first place single-point tool layouts are simple, and as the tools can often be used for roughing as well as finishing cuts the number of tools required to perform a specified amount of work is reduced to a minimum. In the second place single point tools have a free cutting action and exert axial instead of radial pressure on the work, resulting in greater accuracy, not only in bores, but between internal and external surfaces, which is particularly important in turret and capstan lathe work. With single point tools the necessity for pilot bars or floating type holders, together with their attendant influences on the work, is sometimes eliminated, rigidity of the tool being obtained by the use of substantial holders which are supported independently of the work or spindle. For instance on

turret and capstan lathes, the tools can be guided by engaging the turret with the overhead pilot bar instead of extending the holder into the spindle bush. A further feature of the single point tool and the high cutting speed at which it can be used is that it definitely promotes the use of simpler types of machine tool. To increase production with high speed steel the tendency has been to concentrate tools and bring the greatest possible number into simultaneous operation. For quantity production this system is perfectly sound, and still has much to recommend it. At the same time, on account of tool cost and setting-up time, it does not cater

Fig. 16.

for small quantities and the general run of centre lathe work. With cemented carbide tools this defect is remedied, and there are factors which point to the ordinary centre lathe as a serious competitor to the multi-tool lathe for certain classes of work.

In this connection the Magdeburg chip flow lathe was an important development to which some reference was made in the previous paper. This machine had a high spindle speed and a hydraulically operated saddle which was suitable for slide turning operations only. The lathe was primarily intended for the high speed turning of short shafts on which there were a multiplicity of diameters, the tool being set to turn first the largest then the next largest diameter and so on, the feed stroke of the saddles being shortened

to suit, between each traverse. By these means items such as gear-box shafts could be machined as quickly as on multi-tool lathes, but with less tools and setting, the machine showing to great advantage on small quantities. A further development on the same lines is to be found in the Holbrook quick-cut lathe shown in Fig. 16. This was introduced at the Machine Tool and Engineering Exhibition at Olympia in 1934, and is distinguished from the Magdeburg lathe, in that it mounts a surfacing as well as a slide turning member. Its spindle runs in the reverse direction, like the Magdeburg lathe, and is direct-driven by belt from a gear-box mounted in the machine base. The tool slides are hydraulically operated and they can be arranged for taper and form turning as well as for ordinary sliding and surfacing operations.

Associated with lathe work, facilities for quick control are noticeable and are a direct outcome of the development of cemented carbide tools. Under ordinary conditions there are many operations in which loading times, etc., are in excess of the machining time and to reduce them labour saving items such as air chucks are playing an important part. With these, cases are on record where loading and unloading is accomplished without stopping the machine spindle, considerable economies being gained as a consequence. The Herbert Preoptive headstock is another example of development on these lines. In this, changes in spindle speed are pre-selected whilst the machine is running but the speed is not actually engaged until required. Assuming the machine to be running the operator turns a figured dial to the next speed required, the speed ultimately being engaged by swinging a vertical hand lever from left to right. There are many turret and capstan lathe jobs where changes in spindle speed are desirabe and an ability to change speed with such rapidity is a definite economic asset.

For milling operations cemented carbide, as mentioned, is largely confined to facing operations. To facilitate these a recent development is the Ingersoll power pack. Illustrations of this are not available, but it may be described as consisting of a series of standard units which can be quickly assembled in any pre-determined order and applied to a very wide variety of component. The power pack is becoming very popular in motor car factories and from a machinists point of view has the important advantage of flexibility, i.e., by simply re-arranging the units they can be converted to other uses and be constantly employed at maximum capacity.

For fine boring operations the principal objection to use of cemented carbide emerged from the fact that the machine was of special design and only had one spindle. This was due to the oil cooled spindle bearings, which precluded the mounting of spindles at close centres, and the necessity of keeping the work cool when boring to extremely fine limits of accuracy. To expedite the process

Ernst Krause & Co. have developed two, three and four spindle machines. On these, the spindles are still disposed at fairly wide centres but output has been greatly accelerated by the introduction of indexing work tables and similar work holding devices, for bringing alternative cylinder bores quickly into the boring position.

On planing machines it is essential that the tool should not be allowed to trail on the return stroke. To obviate this it is now common practice to lift the tools, by electrically operated solenoids which tilt the clapper box. On machines of this class, apart from the idle return stroke, idle time for work changing can easily be in excess of machining time. To meet this requirement a practice has been adopted of tandem and dummy work tables. The latter are in short sections and can quickly be located and secured to the planing machine tables. In use the dummy tables are loaded separate from the machine, the tables being exchanged when the cutting operation is completed with a minimum loss in machine time.

Effect on Machine Tool Design.

The effect of cemented carbide on machine tool design is much too broad a subject to be approached with any satisfactory conclusions at this juncture and the authors must content themselves by referring to a few outstanding points. In addition to higher cutting speeds and wider feed ranges, extreme rigidity is an all-important factor. In some cases this is obtained by improvements. in the machine and in others by the design of the tools and their holders. On all modern machine tools ball or roller bearing spindles are standard and where really high speeds are encountered the drive is made as direct as possible. In most geared types of lathe the spindle drive is taken through ground tooth gearing, speed changes on the smaller types being obtained through gearing mounted in the base.

Rigidity in bed and slide members has been obtained by stiffening up and constructing the members concerned on more scientific lines, and by adopting more advanced methods of lubrication. In this connection the use of ground beds and covered slide-ways is important.

Milling cutters designed for cemented carbide tipped blades, similarly, are now provided with more rigid support, mainly by extending the steel body in which the blades are inserted to embrace the blades as close to the cutting edge as possible.

Re-conditioning Cemented Carbide Tools.

Before concluding the authors feel it desirable to make some comment on the re-conditioning of cemented carbide tools. Whatever may be the case with high-speed steel tools, it

is certainly a fact that correct angles, etc., and finely finished cutting edges pay on cemented carbide tools. It has been pointed out that cemented carbide is so hard that it cannot be changed in shape except by grinding, and then only by specially selected wheels. The makers of cemented carbide give lists of suitable grinding wheels and have furthermore interested themselves in the development of grinding machines specially adapted for conveniently handling the tools. However, the finish obtained by ordinary grinding is not sufficient to ensure the very best results and a further process of final lapping is strongly recommended. This gives a keen but strong cutting edge which is reasonably estimated as increasing the life between grinds at least four fold and has a proportionate effect on the fine finish which such a cutting edge imparts to the work. The lapping process can be done with an ordinary cast-iron lap and an abrasive such as diamond dust. Alternatively a much quicker method is to use Spedia laps or grinding wheels, which were developed and are supplied by A. C. Wickman, Ltd. These are bakelite bonded and are impregnated with diamond dust. They are supplied as hand laps for touching up the cutting edge of tools without disturbing the machine set-up and also as straight and taper cup wheels. Originally these were used on ordinary grinding machines, but they can now be used to better advantage on special lapping machines developed for their use and having a double ended spindle with universal slide rests in which the tools may be clamped, the rests permitting of adjusting and manipulating the tools with the accuracy and sensitivity demanded of a fine lapping operation.

Discussion, Leicester Section.

MR. H. HALLAM (Chairman): Will Mr. Field please repeat the figures relating to the speeds and feeds of the planer practice as mentioned in connection with the illustration of the latest type "Butler" machine, and also the type of casting to which the figures refer. What struck me at the machine tool exhibition at Olympia was that whilst wonderful speeds were being demonstrated, all cutting was on solid iron castings, which, of course, we do not always get in our own works. It occurred to me that the castings on which the demonstrations were being effected had been specially annealed, which had a lot to do with the success of the tool. In practice one gets very intricate castings these days of very light sections, and I would like some figures of speeds and feeds on castings of this description.

MR. FIELD: The figures referring to planer practice at the works of the Butler Machine Tool Co. are as follows: 160 to 180 ft. per minute on cuts $\frac{1}{2}$ in. to $\frac{5}{8}$ in. deep with a cross feed of $^{1}/_{32}$ in. per stroke. These figures are for cutting cast-iron but particulars of its quality are not available at this moment. In the works with which I am associated we use the latest type of Butler Machine with spiral electric drive and we secure similar figures to those given by Messrs. Butler, when cutting nickel chrome semi-steel lathe beds and saddles with a Brinnel hardness between 230 and 255. Both Wimet and Ardoloy are used for this class of work and both give excellent results. When castings of a fragile nature are to be machined, the work itself will dictate the speed and feed which can be used but one would naturally expect to have to cut somewhat slower and with a less depth of cut and possibly a finer feed. The spiral drive planer however is so rigid that one cannot feel any shock when full speed entry cuts start or finish even at speeds and feeds as mentioned previously. Referring to the question of specially annealed castings for exhibition demonstration purposes, one can only mention that the metal removal figures quoted from actual practice are exceedingly good, without attempting to quote any stunt figures.

QUESTION:

I understood the speaker to say that the temperature of the work was raised considerably when cutting cast iron cylinders with tungsten carbide, but that when cutting solids this temperature rise is non-apparent. I am not quite clear on this point and should be glad of some further information. The other point on which further information would be of interest is that of "fine boring" of cylinders of iron and steel.

MR. FIELD : It is difficult to say with certainty the reason for variations of temperature when cutting thin sections as compared with solids, but the fact remains that when cutting say an 8 in. solid billet, the work remains cold, all the heat being dispersed in the chips. On the other hand when cutting a cylinder say 8 in. diameter, with a 6 in. bore a considerable amount of heat remains in the work. The authors are of opinion that this heat is caused by atomic vibration of the work itself, the thin wall section vibrating considerably more than can the solid billet. It is also interesting to note that cylindrical castings made by the centrifugal process do not get so hot under cut as do similar size castings produced in sand moulds, speeds and feeds being the same in each case, and it would seem therefore that the " closeness " of the iron has something to do with the problem.

QUESTION :

If you require hardness in tungsten carbide tools to machine metals why do you add alloys to reduce the hardness ?

MR. FIELD : The use of alloys other than tungsten when used with cemented carbide results in a lower degree of hardness, without seriously affecting the cutting capabilities. As an instance of this tungsten carbide has a hardness of 86 to 98 on the Rockwell C. scale whilst a molybdenum titanium carbide is 83 to 85. The result of this reduction in hardness is to produce a tougher material of a less brittle nature, thus eliminating to some extent, the tendency to chip at the cutting edge under load.

QUESTION :

With regard to the question of softening these materials by the addition of other alloys, would it not be possible to evolve a material which would be tougher than the ordinary cemented carbides, but harder than the super high-speed steels ? It seems to my mind that a greater percentage of these toughening elements would have this effect, giving a material which would be probably suitable for such types of tools as milling cutters which seems to be a weak point in the application of cemented carbides. This is probably a matter more for the manufacturer of the material than Mr. Field, but perhaps he can give us some information on the subject. There would be a very wide sphere of utility for such a material if it could be made.

MR. FIELD : This question is really only answerable by a metallurgist, and I am unable to even attempt an answer. It is, however, a fact that Stellite, which is a cast cobalt-chromium-tungsten alloy, having a Rockwell hardness of 60 to 61-5, will give excellent service when used as inserted blades in milling cutters. It will not give quite the cutting speeds as the cemented carbide group, but it will cut at faster rates than high speed steel.

QUESTION:

Is it true that in Stellite you get " blow holes " and other faults which are not apparent in the cemented carbide group? Another point is that if you fix tips in the shanks by cement, the tips are inclined to crack in use. This is my experience but this trouble is largely overcome if the braze is affected by copper.

MR. FIELD: Stellite is a cast product and in some instances faults in the structure of the material are apparent. In the Stellite 40 metal, however, there is considerably less of this type of trouble than there was a year or two ago. More careful methods of casting are now employed. With regard to the question of tips cracking in use I have never seen this happen with any of the cemented carbide group, except when the machine has stalled under cut, but on the other hand my own experience has been only with tips fixed by copper.

QUESTION:

I would like to ask whether the reason for not making form tools in cemented carbides is because of the difficulty to grind them or whether it is because the broad edge of a form tool will not stand up to the load of the cut. Also I would like to know the section of the tools used for shaping or planing.

MR. FIELD: The position with regard to form tools is largely a question of cost, plus of course, the difficulty of grinding a complicated form. There are many form tools tipped with one or other of the cemented carbide materials in every day use and, as form grinding facilities improve more and more, form tools will be used.

Referring to the section of planing machine tools, the tools used in the example given in the paper are $1\frac{1}{4}$ in. by $1\frac{3}{4}$ in deep, the tool tip itself being about $\frac{3}{8}$ in. thick.

Discussion, Southern Section.

MR. WESTBROOK : I should like to know if Mr. Field has had experience with the machining of stainless steel and what lubricant he used.

MR. FIELD : I think probably Mr. Westbrook has had more experience than I have had with these materials, but I did write to Messrs. Richards asking for their experience on similar work and the same subject was raised in Leicester.

With regard to the machining of stainless steel, I have pleasure in giving an extract from a report by a demonstrator : " I have made a very interesting test ; several light cuts were taken and in one of these the diameter was reduced by .00075, i.e., $\frac{3}{4}$ of 1/1000 in. This was a perfectly clean cut, giving a striking example of Cutanit properties. This was with S.80 with which you are no doubt familiar." Arising from my own experiments, the one thing which seems to be more important than the actual cutting speed is that you must use an automatic feed and you cannot expect good machining unless you *do* use an automatic feed. With regard to the type of coolant, I cannot answer conclusively because practically all my experiments have been done without any coolants.

MR. LAYZELL : I should like to know, taking your last slide of a lapping machine, whether you consider it essential to fix the tool as most lapping that I have seen the tool has been held by hand.

MR. FIELD : That is a very important question, as unless we have machines in which both the grinding and lapping are done by clamping the tool it will not be successfully handled. You cannot get the best results by holding by hand. Face grinding and lapping are allied subjects.

MAJOR STANFIELD (Section President) : Are there any peculiarities between the tungsten carbides of the various makes regarding chipping ?

MR. FIELD : One has to bear in mind the surrounding conditions, such as intermittent cutting and the nature of the tools. Under some circumstances tungsten carbides will chip more readily than tantalum carbides.

Discussion, Eastern Counties Section.

MR. T. A. FAULKES: What can be expected with tungsten carbide on existing machine tools and also in connection with automatics? Further, what information could be given regarding cutting rakes?

MR. FIELD: The first question is of course a very pertinent one. I would like you first of all to appreciate that I did not give the paper as a machine tool maker, but as a production engineer, trying to give you some of the experiences that have fallen to my lot. Obviously all you could expect from tungsten carbide on existing machines would ensure cutting edge holding capabilities rather than high speed capabilities.

Regarding the second point, that is, a combination of tungsten carbide on automatics involving such operations as screwing or reaming, there of course you have to turn to modern machines properly designed for this class of work. If you will examine them in detail you will appreciate that in addition to giving high speed ranges, they also give you lower speed ranges. I have actually seen examples of tungsten carbide chasers for producing screw threads, but only on non-ferrous metals.

The question of cutting rakes was brought out both at Leicester and Southampton, but frankly it is much too deep a subject to try and cover in a general paper. It needs an entire paper on its own, because the cutting rake varies and is disproportionate to the advantages to be met in other directions. Generally speaking the front clearance of the cutting tool should be less than high speed steel, thus retaining as much of your shank material as you can get. The top rake should be approximately one half of that used on high speed steel tools.

Cemented carbide has very little inherent strength. You must prevent reaction to this by the strength of the shank beneath the tip.

MR. MURDOCK: Referring back to the question of using tipped tools on old machines, it is obvious that you do get an advantage. Is there any difference in power required between various types of tipped tools, that is to say given the same type of tool on the same job? Also, have you had any experience with unskilled labour, particularly boy labour with tipped tools?

MR. FIELD: The first point arises from the first remark I made. It is possible to get advantage from tungsten carbide from old machines. With reference to the amount of power, that rather brings you back to the previous answer again, as it is closely allied

to cutting rakes. Some two years ago, some very interesting experiments were made with a series of tools, prepared from each of the materials then available with the same rake angles, same section and same machine, on some steel billets.

This particular instance showed a difference in power absorbed of about 10%. A little later some further experiments were made with a change of rake angle, and it was found that different cemented carbides need different rake angles to effect certain cuts and that they all need the same amount of power to remove equal quantities of material.

The question of unskilled labour using tungsten carbide material is a serious point, and in very few factories is it really successful We ourselves in Birmingham use a skilled man with an expensive material, rather than give it to a boy. A boy might be entrusted provided speed and feed are set by someone who understands the material. It is being used fairly successfully although in most cases where I have asked that question they are a little hesitant in saying that unskilled labour can use it to advantage.

MR. G. WOOD : I would like to ask if the lecturer has had any experience with carbide tool steel in connection with the turning of copper with mica inserts, and producing a high degree of finish such as required in a commutator. On one of the slides you showed the machining of a Metropolitan-Vickers yoke. As a matter of interest I should like to know what was the time for machining the bore of that yoke.

MR. FIELD : I have no experience with regard to the turning of copper, with mica inserts. A properly lapped tool will give a magnificent finish to copper at high speed, preferably cutting dry. I cannot give you the actual time for the yoke, as we were looking for cutting speeds and feeds only.

MR. BALDRY : Have you had any experience in the cutting of other materials ? I am interested in the slicing of xylonite from a block into thin sheets to be free as possible from knife lines. I wondered if you had had any experience in this ?

MR. FIELD : I am afraid I have not had any experience with that material, and naturally cannot give you any opinion on the point. With regard to the cutting of non-ferrous substances, those of you who have a copy of the Institution's *Journal* for 1933 will find reference to this there. Tungsten carbide cutters have been experimented with for cutting certain woods. Also of course tungsten carbide is being used extensively by stone masons in the turning of pillars in stone, marble, etc. While we are prone to think our metal removing problems are the only ones, there are other spheres in which tungsten carbide can be used, such as drills for coal mining, etc.

MR. F. KEEBLE : What is the correct kind of tool centre to use when turning at very high speeds ?

MR. FIELD : You must use a live centre. It is no use trying to use an old fashioned dead centre. There are 20 or 30 types of live centres which can be obtained from different makers for use on lathes. It must be a ball or roller bearing live centre if you are going to get any advantages. On very large lathes which are being used (I have in mind a 24 in. geared head centre lathe with 40 ft. bed used in a works in the North for turning non-ferrous liners) they are turning somewhere in the region of 800 ft. p.m. and in the early days they had trouble with their live centre. It was redesigned and a very heavy spring was embodied behind the centre to allow for work expansion during cut.

MR. KEEBLE : I was wondering whether there is any recent development in a high speed steel tip being attached to a carbon steel centre.

MR. FIELD : I have seen a number of experiments, but I do not think they are worth while.

MR. RACKHAM : I was wondering if the lecturer could tell us anything about tungsten carbide tipped drills for cast iron or steel.

MR. FIELD : I can answer that in one word,—no, they are not successful. They can be used for drilling ebonite or light materials where there is no load as the material is soft, but I know of no case where tungsten carbide is being used on drilling machines. There is no support behind cemented carbide tips when attached to a twist drill.

Discussion, Birmingham Section.

MR. E. P. EDWARDS (Chairman): Two small points occurred to me during the early part of Mr. Field's paper. One was, the very remarkable saving in cost on workpieces which he illustrated. I should like to ask him whether the relative cost of tools was taken into account in the overheads, or whether they were so infinitesimal that it did not matter?

MR. FIELD: Replying to the question which Mr. Edwards has put to me, in the examples shown on the screen to-night, 12% has been added to the purchase price of the machines to cover the cost of tools for a four-year period. Some figure had to be taken, and I am not prepared to say that 12% would be enough or too much, but that is the figure actually taken.

MR. I. H. WRIGHT: Mr. Field's paper has appealed to me very strongly indeed. I was raised as a machinist, but my machinist days finished just before high speed steel came in, and during the early days of high speed steel I was often very envious of the people who were making these interesting experiments and I always had a very critical attitude towards high speed steel. My experience had been with carbon steels, and I thought that high speed steel was not a cutting material—it was a metal shifting material. Now in recent years tungsten carbide has come along, and I believe we have got back to a cutting material. In my opinion, to take a cut of 0.010 in. with a very fine cutter on any machine whatever, we have really got to have a cutting material; it could not be done with a high speed material. The examples that Mr. Field has put before us to-night where very light finishing cuts are taken on long cylindrical pieces are, again, proofs that the action really is a cutting action. I am very glad that it has come along, and I am envious, personally, of the men actually concerned with running machines and getting experience on these lines.

With regard to the cutting action, I would like to ask Mr. Field a question carrying one of his statements just a little further. In using high speed steel on fairly heavy cuts, generally on mild steel, the length of the chip that comes off, if measured, will probably be only half, or less than half, the circumference of the work that comes off. If you look at that chip, you will see it is composed of crushed up triangular prisms, just attached to each other. Mr. Field said that the length of the chip was equal to the circumference of the work. Of course, I do not think it is quite that, but can Mr. Field give us any actual measurement that may ever have been

made as to the relation between the length of the chip and the circumference of the work from which it has come ? There is a great deal behind that, I think. In the high speed steel variety a small amount of the power used was actually used to direct the vibrations of the cutting tool away from the vibrations of the work, but the greater part of the horsepower put into it was used up in crushing and distorting and in generating heat in that way in the actual chip itself, and it seems to me if it is proved that the chip is very much less distorted than it was in the case of the high speed steel, chip, that accounts for a great economy in horsepower.

I think the figure he gave of 2 cub. in. per minute for mild steel was very favourable. It accounts for that, and also for the fact that work does not heat up anything like as much as on high speed steel in relation to the rate of metal removal, which is what we ought to consider, and that means that a lot of force is going to the work in relation to the cutting edge, and is a big contributon towards the accuracy possible with these carbide cutting materials as compared with the high speed steel. It is rather an involved question, but I am sure the point is worth taking up, and Mr. Field has much better opportunities than I have of doing it.

MR. FIELD : I shall agree with Mr. Wright on the majority of what he said. First of all, the tungsten carbide or cemented carbide group are cutting materials as distinct from metal removing materials. Mr. Wright was interested, he said, in the very light finishing cuts which I showed, and which were 0.006 in. deep. This brings to mind many other details which we had to sort through with regard to the machining of stainless steel, which, as you all know, is rather a difficult material to cut.

This is an extract from our files. " Several of the executives present were rather dubious about what a certain tungsten carbide tool could do on stainless steel S.80, so a piece of this material was put into the machine and a cut was taken of 230 ft. per minute, 0.015 in. deep, without any trouble. Several light cuts (always difficult on stainless steel) were taken, and on one of these cuts the diameter was reduced by 0.00075 in."

I cannot say I have ever been down quite as low as that, but we have taken cuts of 0.001 in. and continued to take up those cuts.

Mr Wright's involved question with regard to length of chips, is a subject which deserves a paper on its own. I find it rather difficult to answer because I have not actual figures to quote to him, but I must retort by saying that if he examines the back of the chip, it is always the thing that tells one most history. As Mr. Wright says, if one examines a chip produced by a high speed steel tool, it is a series of very jagged craters, and consists of a number of chips of minute length which have been crushed up together.

Whereas, if one takes the same speed and feed on a tungsten carbide tool, the back of that chip is highly polished, and shows no signs of cratering. That is the reason why these new materials do not generate heat. That heat one gets with high speed steel is largely generated by the crushing action of the chips, and not by the cutting action itself. The heat is considerably less with tantalum cutting materials, than with tungsten carbide. If one tests tungsten carbide to destruction, the top of the tool is cratered and the back of the chip is badly crushed. If, on the other hand, a tantalum carbide tool is put to the same test, the back of the tool is more highly polished for a longer period than it is with the tungsten carbide tool, and it is with that highly polished chip and non-crushing action that the length of chip production is equivalent to the periphery of the job, multiplied by the distance of travel. I have not taken any actual measurements, and it is, I imagine, a rather difficult job to take measurements.

A VISITOR: I should like to ask the lecturer if he has allowed the cost of reconditioning machines to recondition tools, and, secondly, if he has taken into consideration increased length of time required to recondition Wimet or Ardoloy tools?

MR. FIELD: I take it your question is actually one of the cost of reconditioning tungsten carbide tools as compared with high speed steel tools? I have taken out so many costs, and they are so contradictory that I hesitate to mention them, but on costs quite recently taken out, the tungsten carbide tool, say 1 in. square in section, with a tip on the end, in one case cost 1d. to recondition and in another case 4d. to recondition. It entirely depends on the condition of the tool when you want to recondition it. I should say, with tungsten carbide, recondition before it wants it and you will find it cheaper and continue to produce economically. I am sorry I cannot give you any precise figure, but if, as I say, you will recondition it before it wants it, (it is not a very difficult thing to do) on constant production your grinding will be relatively cheap and in some cases you will be able to recondition your tool on your burnishing lap rather than go to your rougher wheels.

MR. POWELL: I should like to ask Mr. Field if he will give us a little information in respect to the application of Wimet or Ardoloy to roller box turning. I have in mind a little experiment with Wimet and Stag Major. My experience was that I found Stag Major safer. I found that I could take a very much higher feed with Stag Major, but Wimet required a higher speed and slow feed, and I actually got the piece off in less time with Stag Major than with Ardoloy or Wimet. There is another instance of a job that is being run to-day at a 1,000 ft. per minute with a very light cut on mild steel. There is no other steel I know of that will stand up to that.

From observations I have made, under some conditions Widia is quite satisfactory, but in that case I do not think so.

MR. FIELD : Replying to Mr. Powell's last statement first, when he began to talk of a 1,000 ft. per minute, of course there is no high speed tool steel that will get anywhere near that figure on any job I have ever seen, including bronze and other metals, but there is one thing to be remembered in that connection. It depends almost entirely on the machine tool you are using as to the service you are going to get from any particular brand of cutting tool. I hold no brief for any manufacturer of tungsten carbide at all, and I would say without fear of contradiction that there is no " best " tungsten carbide. There is the best for certain jobs and for certain materials, and if you go into any shop using it extensively you will find they are using at least three different makes. There are other materials which have not been mentioned to-night which are rapidly coming to the fore, and I think there will in the future be as many brands of tungsten carbides as there are high speed steel, and if there are as many salesmen trying to sell them, I shall have to get a secretary to help me out !

Reverting to the first question, I have, honestly, yet to see a successful application of tungsten carbide to roller box turning tools. The fact is that tungsten carbide has very little inherent strength so far as its tip is concerned. If you chip a tool at a high speed like that, you will probably cut into the roller box tool : you will certainly spoil your rollers. There are, however, a number of developments taking place, and in a few months at the outside we shall be using it successfully in roller steady turning tools. I agree with Mr. Powell who says that, at the moment, good brands of high speed steel are better for roller box tool work than tungsten carbide tools.

MR. H. BLACKMORE : I should just like to mention an instance where great advantage has been found with tungsten carbide cutting tools, on a boring machine over fifteen years old, using 7½ h.p. producing cast iron tractor wheels weighing 2 cwt. each. The time was reduced by more than half and the finish of the job was greatly increased by the use of tungsten carbide tools.

MR. FIELD : I hope I have not given the impression that tungsten carbide cannot be used on existing machines—that would be wrong. What I do say is, it can be used to better advantage of machines which have been designed to use it. In no case to-night has what might be called the special machine been illustrated. They are all standard machines built in quantity, but they have been designed or re-designed for tungsten carbide cutting tools giving greater speeds, and having capabilities of absorbing greater horsepower for metal removal.

MR. L. P. WILEY : I have not any applications for tungsten

carbide tools at present, but nevertheless I feel very interested in the subject. It seems to me that the recent advances have principally been in the development of machines particularly suitable for that type of tool, and also the introduction of titanium-tantalum and other elements to make them more suitable for machining steel. What I should like to know is, is there any prospect in months or even years of giving us form tools ? I have in mind in particular chasers for threading.

I was very pleased to hear Mr. Field say that in a few months time we may have tungsten carbide applicable to roller steady boxes, which means that we may look for a greater degree of stability in them, but I should think even then we shall be a long way from any possibility of a tool with sufficient strength to stand up to a job like chaser cutting. Even now, chasers are made from high speed steel, and then, apart from the question of getting material so that it will not chip, there is the great difficulty I should imagine, of getting the tool centred, and getting the necessary accuracy of form.

Mr. Field : Mr. Wiley raises rather an important point, and I think you will all appreciate that in a paper of this type there must be some small points we have missed. The only difficulty I see with regard to form tools is the difficulty of satisfactorily grinding them. The same remark applies to chasers. I have actually seen a screw-cutting chaser in action on brass work, producing over 40,000 pieces without being re-ground, and with the modern methods of grinding I think we can expect to get forms tools, in the not too distant future, to give us exceedingly good results.

I do not think existing materials will be used, but the metallurgical side of this business is really down to its job.

Mr. C. K. Hughes : We have discussed Widia tipped turning tools and cutting tools. May I ask if this material has yet been introduced in presswork, for blanking, and drawing ?

Mr. Field : To my knowledge, no. It is a sphere of the production world a little outside my own experience. Some gentlemen present may be able to enlighten us.

Mr. Clinch : I do not think that has been attempted yet. The crushing strain is too great and the pressure on the tools too great. There is one point I should like to bring up. I notice carbide tools have very often been condemned because the people have chosen the same section tool that they would have done with high speed steel. Where it is an inch tool, they have chosen an inch carbide tool, whereas it should be an inch-and-a-quarter, because the actual strength of the tool is only about 34%, and I do not think people realise how important it is to get a bigger size of tool.

Mr. Field : That really important point was touched on to some small extent in the paper. The strength of the material itself as a

cutting tool is, of course, only the strength of the supporting tool which is underneath it, and I think it will be found, on examining a modern machine designed to use this material, that the tool-carrying members are of a much deeper section themselves to allow the use of tool shanks of heavier construction. I would suggest to those of you who are trying to tip your own tools, do use a really good shank material, say, .8 carbon steel, to give you some rigidity in the supporting member under the tip.

Discussion, Preston Section.

MR. C. T. SKIPPER (Section President): I think you will agree that we have had an opportunity of hearing a very interesting lecture dealing both with the manufacture of carbide tools and with their application to production. From a production point of view they have undoubtedly been revolutionary, and I think the machine tool maker is to be congratulated on the rapid way he has designed machines so that full advantage can be taken of these tools.

MR. J. HINDLE: I should like to ask the lecturer this question: Where a machine is not provided with an ammeter, what length of time would he consider a carbide tool could be used without requiring grinding?

MR. FIELD: That is rather a difficult thing to say, because it presupposes a knowledge of the operation. But on steel I think you should take it this way: when your swarf begins to discolour it is time to re-grind the tool. I am afraid I cannot answer that question accurately without knowledge of the actual conditions obtaining.

MR. FRASER: The lecturer states that with intermittent cutting, there is no chipping of tools. Unfortunately my experience has been quite the contrary. I find that on steel we invariably get chipping. I do not know the reason. We are using tipped tools, but at the same time this has actually occurred. The particular operation is on a boring mill with a steel worm spider. I should like to ask also for the lecturer's views on the question of the machining of mica insects after assembly in the commutator.

MR. FIELD: I am at a loss to understand the difficulties being experienced by Mr. Fraser, as in my experience intermittent cutting is being successfully operated without chipping. With regard to the question of mica insects, mica is one of the worst materials I know for abrading tungsten carbide, and I have not seen that operation successfully performed yet.

MR. SCAIFE: I have enjoyed the lecture very much. I have heard it once before, but I must say that Mr. Field has since then improved the paper out of all recognition. He has evidently kept right up to date with research on the subject. There is just one point I should like to mention. In one of the earlier slides I rather gathered the impression that diameters could be finished more efficiently with a carbide tool than with a grinding machine. I have in mind a case where a component about $1\frac{1}{4}$ in. long and approximately $^{7}/_{16}$ in. diameter is being finished at the rate of 198 pieces

per hour to a tolerance of plus and minus 1/10.000 in. I wonder if Mr. Field would like to try that with a carbide tool.

MR. FIELD : I am sorry if anything I said appeared to be decrying grinding in any way ; that was not the object of the comments. The idea was to perform the operations without having to transfer to a grinding machine. The fact remains that it is practical politics in the production world to-day to finish certain things in this way because of the very small scratch depth as compared with commercial grinding.

MR. WILCOCK : I think you will all agree with me when I say that this lecture has been very capably handled indeed by Mr. Field. Should this lecture be typical of what we may expect in the Preston district there is not the slightest doubt whatever that the Preston section is going to be one of the foremost sections of the Institution of Production Engineers there is in this country. Mr. Field is to be warmly congratulated upon the consideration and thought which he has devoted to the preparation of the paper and upon the detail given in the lecture ; he leaves almost nothing to, shall we say chance and very little for the critic to take up. However, it gives me very great pleasure indeed to have extended to me the honour of proposing a very hearty vote of thanks from this meeting to Mr. Field for the labour he has expended on his excellent lecture.

MR. CLAYTON : It is indeed a great pleasure to second the vote of thanks to Mr. Field for his very interesting and very instructive lecture. As the chairman has pointed out, the advancement that has been made in tool steel during the last few years is rather remarkable. The high cutting speeds obtaining nowadays would never have been dreamed of a few years ago. I think the chart Mr. Field showed on the screen was very interesting, I mean the one showing the cost of the high speed steel on the old and the more up-to-date machines. Even with the highest depreciation figure and the highest on-costs and operating charges, the capital recovery life of that machine was halved. It means that the manufacturers can keep more up-to-date and renew his plant more often, and surely that means more work for the machine tool maker and more work for the engineer. I have very great pleasure in seconding the vote of thanks.

Discussion, Manchester Section.

MR. KING (Section President) : It is very gratifying to hear this lecture to-night. Some thirty years ago I was in the Lab. of this very building engaged on some experiments under Dr. Nicholson on High Speed Cutting Tools. I think that is rather ancient history in view of what we have heard. At the same time, there is even to-day in process in this College a Committee which is investigating the life and durability of cemented carbide tools.

There are one or two points which appeal particularly to me. One of them is the tremendous advance which has been made in cutting steel by cemented carbides. All of us here are familiar with the latest practice in cutting cast-iron and non-ferrous alloys, but cutting steel components having intermittent cuts has really only been developed within the last two years or so. Many of the examples put on the screen to-night have given us a lot of food for thought.

Another point that interested me greatly was the illustration of a balanced cut arrangement, whereby a heavy cut can be taken over a long surface, whilst drilling at the same time. Thereby the one balances the force of the other and so speeds up the job generally, and also considerably reduces the idle time.

Most of us are perhaps engaged on small quantities per batch, but I think the point was very well brought out in the lecture that on an expensive set-up there is no doubt whatever that the cemented carbide tools lasts very much longer. For instance, in the case of bores to be produced to the finest limits possible, grinding of the tools is necessary only about once a day. That in itself is a tremendous saving quite apart from any high speeds.

MR. ECKERSLEY : In common with Mr. King, I must express my admiration for the way in which Mr. Field has put forward the modern technique of using cemented carbide tools. At the same time I must point out that I think, whilst Mr. King mentioned that thirty years ago he was engaged on research work on high speed tools, it is necessary to forget all we know about high speed steel tools when considering cemented carbide, just as thirty years ago it was necessary to ignore carbon steel tools practice. Actually the technique is considerably different. If high speed tools are superseded by an exactly similar design of cemented carbide tools, without regard to several factors, trouble is amost certain to occur.

A point not mentioned during the lecture is that recent experimenting shows that small top rakes are found to give the best results on

steel, typical rakes being eight degrees for free cutting mild steels down to three and a half degrees for high tensile steels, and for extreme cases even smaller rakes.

Another essential in getting the best out of tungsten carbide, arising out of the lack of tensile strength, is that the tool must be designed so that a good surface of tip is presented in the direction of the cut ; in other words, to use a corner for cutting is asking for trouble. A large shear strength in the direction of the cutting pressure is advisable.

I was very glad to hear Mr. Field state that the old idea of fine cuts being essential has proved a fallacy and heavy feeds are quite possible provided there is maximum rigidity in the machine, with which I am in entire agreement. Further than that, it is better for the tool to have a broad cut so that the unit pressure along the cutting edge is low. Cemented carbide can only be used at present in the form of a tipped tool, so that the pressures must be so placed about the tip of the tool that the centre of pressure is as far behind the cutting edge as possible.

With reference to carbide tools on automatics : I think Mr. Field ought to have pointed out that big chip clearances are definitely advisable.

As far as wearing properties are concerned, cemented carbide is rather unqiue, as all of you are probably aware, and is successfully applied to those points where high abrasion and short life are normal such as precision gauges, and cam followers. That is a feature which should not be overlooked.

A lot of users are afraid to apply cemented carbide to intermittent cutting. That is a fear which can be eliminated by judicious design of the tool. It is essential that the chip pressure be towards the rear of the tip : in other words, use a deep cut and have a good margin of power. Under the correct cutting conditions there is little risk of tool breakage during intermittent cutting.

MR. FIELD : I would like to express here and now my very great thanks to you for the admirable reception you have given to this paper. I would like to point out that a number of the points which Mr. Eckersley has brought forward as fundamental were dealt with in the original paper, and we tried to avoid repetition.

MR. MILNER : How does Stellite 40 compare with cemented carbides ?

It may be interesting to the audience to know that we have in use a Wimet tipped milling cutter which is re-ground about once every three months, the cutter being in continuous use on cast-iron.

Regarding the metal removing capacity of cemented carbides, when I have been designing machine tools, I have always allowed for 1 h.p. for each cubic inch of steel to be removed. I find that

Mr. Field's are exactly double this, which is certainly worth making a note of.

MR. FIELD : Stellite 40 does not exactly compare with tungsten carbide as regards cutting capabilities. There is quite a future for Stellite 40 on some old machines where you cannot use your tungsten carbide to advantage. Under those conditions Stellite 40 is an exceedingly good tool. It has a distinct advantage that in its own section it is stronger than tungsten carbide. As a metal removing tool it is comparable in no way with tungsten carbide.

MR. DAVENPORT : Will Mr. Field please comment upon the comparative cost of carbide tools and high speed tools, as used on high speed light machines. I have in mind cutting machines where the life of the tool generally is very light in proportion to what we have been led to believe carbide tools will do. Can Mr. Field give us any information with regard to the effect upon the life of the tool of the various cutting compounds ?

MR. FIELD : Regarding the question of the actual cost of the tungsten carbide tool and the relative cost of a high speed tool in the same section, the whole thing revolves around the increased production you can get on the machine, as I have tried to show you on the charts here to-night. The cost of the cutting tool does not matter. Not only were you shown a recovery of the capital cost on your new machine in five years : you were also shown an increased profit . The cost of the cutting tool itself is infinitesimal (that is my opinion), compared with the advantage you are getting from the new cutting materials. The cutting tool itself is nothing —merely a means to an end.

There is no need to use cutting compounds when using tungsten carbide tools. Heat is generated when using high speed tools due to the affinity of the chip for the tool. Ninety-five per cent. of users of cemented carbides are cutting dry on steel.

MR. F. W. SHAW : Suppose that before the advent of tungsten carbide tools the machine tool people had made equivalent improvements to their machines, what would then have been the advantage of using tungsten carbide ? I do not suppose that on any of the small jobs the cutting time exceeds more than half the total, so that all you can possibly save with your tungsten carbide is on the half time, not on the total time. If you are cutting twice as fast with your tungsten carbide, you are saving 25% of the time— not more. But most of the examples we see of the savings supposed to be effected by tungsten carbide are drawn in the region of 50% or 75%, but that is not due to the tungsten carbide tools, but to the improvements in the machine tools which could have been made if tungsten carbide had never been introduced.

MR. FIELD : Mr. Shaw is perfectly correct about the cutting time of any job not being a large proportion of the whole time, and

goes on to blame the machine tool makers for this condition—well, we all know that Mr. Shaw was a machine tool designer himself!

Regarding cutting time, there is a lot of reflection on the user of the machine as well as the machine tool designer, there being many, many instances to-day where loading time is infinitesimal compared with cutting time. I think Mr. Shaw is slightly out of touch with really modern production when he criticises that.

MR. MILLINGTON: Does Mr. Field consider it advisable to put an ammeter on each machine, in order to indicate when the tool is losing its edge. Also are there any developments in respect to tipping cutting edges of large drills with tungsten carbide.

MR. FIELD: For every motor driven machine an ammeter on a metal removing machine is a very wonderful investment, because on long cuts, with a material which is to some extent uncertain, possibilities of chipping must always be regarded from every point of view, and only an ammeter will give the first indication of a tool giving way.

Regarding drills, I have yet to see a "tipped" twist drill that could be marketed. The design is against it. There is no strength in the formation of a twist drill to allow for the backing which tungsten carbide requires.

Spear point drills can be successfully used when tipped with cemented carbide, but these are very expensive and not yet practical because of the price. Undoubtedly the time is coming when the strength of cemented carbides will be considerably increased and I believe that in the not far distant future twist drills, taps, and dies will be made in this particular class of material.

MR. INGHAM: In the first place, what I am going to say is not in the form of a question but in the form of a useful suggestion. We use cemented carbide tools and in common with most other people have trouble due to their being abnormally brittle. As you are aware, they are very bad conductors of heat, and we have found in the grinding, when the tool is brought in contact with the grinding wheel face heat was generated, and we used to get cracking and chipping. It led us to make a small projection of the tungsten carbide beyond the tool shank. It is useful for users of cemented carbide tools to heat the tool slightly before grinding. I make that merely as a suggestion following a very excellent paper.

PAPERS SET AT THE GRADUATESHIP EXAMINATION, APRIL, 1936.

NOTE.—Candidates were required to answer only one of the three following Papers: Construction of Machine Tools and Jig and Tool Design; Physical Metallurgy and the Treatment of Metals; The Application of Electricity to Production. All other Papers had to be answered.

CONSTRUCTION OF MACHINE TOOLS AND JIG AND TOOL DESIGN.

FRIDAY, 17TH APRIL, 1936. (10-0 A.M.—1-0 P.M.)

Examiner: J. LOXHAM, M.I.P.E., A.M.I.MECH.E.

Candidates are allowed to attempt FIVE questions only, of which at least one must be selected from each section.

The maximum number of marks obtainable for each question is shown in brackets.

SECTION A.

1. Describe how you would thoroughly test the accuracy and cutting capacity of *either* a re-conditioned 6 in. precision tool-room lathe fitted with collets, face plates, chucks, etc, *or* a re-conditioned Universal milling machine fitted with vertical attachment and dividing head.

Three days of eight hours each are allowed for the test and standard inspection test bars, indicators, tools and gauges are available for use on the test. (24)

2. The operation of turning a crank shaft on a centre lathe fitted with a special fixture takes four hours. A special single-purpose machine costing £1,500 would perform the operation in twenty minutes.

Describe how you would further investigate this problem in order to ascertain whether the purchase of the special machine would be a profitable investment. (14)

3. Show by means of a layout drawing the selection and location of machines you would recommend for a tool-room employing about 75 men and engaged on jigs, press tools, and small tools and gauges. (14)

SECTION B.

4. Describe by means of a sketch the construction of either a jig boring machine, or a universal cylindrical grinding machine, or a modern shaping machine.

Indicate on the sketch the points of control, the points where wear is likely to occur, and the dimensions of the machine which determine its capacity. (24)

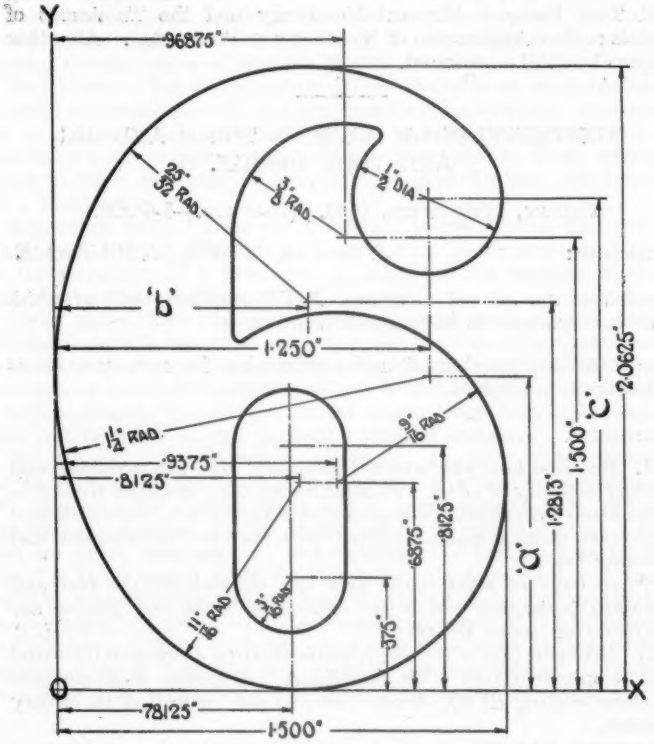


FIG. 1.

5. Describe by means of sketches and suitable notes, *either* the generating principle employed by both the Sunderland and the Fellows type of gear generating machines, *or* the operating mechanism for the turret, and the forming and parting off slides of a single spindle auto screw machine. (14)

6. To facilitate the marking out of the die for producing the figure six, shown in Fig. 1, it was necessary for all centres to be dimensioned from the two datum lines, OX, OY.

Calculate the lengths a, b and c.

NOTE.—At the point where two curves join, they must be tangential to each other. (14)

SECTION C.

7. Illustrate by means of fully dimensioned sketches any five of the following :—

(*a*) The effect of variations in the height of a plain turning tool upon the angles of clearance and top rake.
(*b*) 1½ in. diameter core drill.
(*c*) Circular form tool as used on auto screw machine.
(*d*) Bar turning tool as used in roller type tool box on turret lathe.
(*e*) Plain tool holder suitable for ⅝ in. square tool bits.
(*f*) Single pull broach for standard keyway in 1 in. diameter hub.
(*g*) Tungsten carbide tipped tool for rough turning cast iron on heavy duty lathe.
(*h*) 9 in. chuck suitable for mass production work (outline drawing only). (14)

8. Make *either* an operation layout and simple outline drawings of the tool layouts and jigs you would recommend for the quantity production from bar of a No. 4 to No. 3 morse taper sleeve, *or* a general arrangement drawing of a compound press tool for the production of the figure six (Fig. 1) referred to in Question 6, Section B. Briefly describe what precautions you would take during the manufacture of the press tool to ensure accurate lining up. (24)

9. Describe the relative advantages of jigs made from cast iron with steel plates attached by means of screws and dowels, and mild steel jigs fabricated by welding. Give examples to illustrate your answer. (14)

PHYSICAL METALLURGY AND TREATMENT OF METALS.

FRIDAY, 17TH APRIL, 1936. (10-0 A.M.—1-0 P.M.)

Examiner : T. G. BAMFORD, M.Sc., A.I.C.

Answer SIX questions only.

1. Compare grey iron castings and malleable iron castings as regards :—

(*a*) Mechanical properties.
(*b*) Microstructure.
(*c*) Uses.

2. State in each case what types of steel you would select as suitable for the following purposes :—

(1) For manufacturing small gear wheels.
(2) For the crankshaft of a light car.
(3) Dies for a Bakelite Moulding Press.
(4) For the valves of an aero engine.

Give reasons for your choice.

3. Give typical compositions and write an account of the properties of any two of the following alloys :—

(*a*) A brass suitable for hot pressing.
(*b*) Phosphor bronze.
(*c*) An aluminium alloy suitable for crankcases.
(*d*) Aluminium bronze.

4. State what alloys are used for bearing metals and explain what are the essential properties of a good bearing metal.

5. Give a brief description of the arc welding process and explain what precautions you would take in arc welding high carbon steel.

Describe two examples of engineering structures which are fabricated by welding.

6. Explain the meaning of the term microconstituent as applied to alloys. Name any three such constituents which are to be found in iron and steel and describe how you would proceed to identify them.

7. Describe fully the method by which a tensile test is carried out on mild steel in order to determine its yield point, ultimate strength, elongation and reduction of area.

Give carefully made sketches of the types of load deformation curves you would expect to obtain from any two of the following :—

(*a*) Mild steel.
(*b*) Muntz metal rolled and annealed.
(*c*) A high carbon steel.

8. Sketch and describe the working of a modern type of furnace suitable for the melting of cast iron.

9. What special properties are required in cutting tools for use in the machine tools of a production engineering workshop.

Give examples of two alloys suitable for this purpose and explain briefly what methods are available for testing the cutting qualities of these alloys.

10. Describe a pyrometric installation suitable for measuring and recording the temperature of a gas-fired furnace used for annealing steel strip.

THE APPLICATION OF ELECTRICITY TO PRODUCTION

FRIDAY, 17TH APRIL, 1936. (10-0 A.M.—1-0 P.M.)

Examiner: C. F. PARTRIDGE, B.Sc. (ENG.), M.I.E.E

Answer FIVE questions only.

1. A 50 h.p. motor is acquired for the main shaft drive of a machine shop.

Indicate the arrangements you would make for (*a*) installing the motor; (*b*) transmitting the motor power to the main shaft; (*c*) controlling the input to the motor. You may assume either a 440 volts direct current supply or a 400 volts 50 cycles per second alternating current supply.

2. Answer either (*a*) *or* (*b*).

(*a*) Define the terms: Lumen; Mean spherical candle-power; Foot candle; Reflection factor; Angle of cut-off.

(*b*) Describe in detail the control gear required for a large advertisement sign of the gas discharge type.

3. Enumerate the various losses in either (*a*) a shunt direct current motor, or (*b*) a multiphase induction motor.

State how each individual loss is affected by the load on the motor.

4. (*a*) Define the term "earthing."

(*b*) Under what conditions would you consider "earthing" necessary?

(*c*) What would you consider constituted a "good earth"?

(*d*) What steps would you take to determine whether "earthing" had been efficiently carried out in any given case?

5. Answer either (*a*) *or* (*b*).

(*a*) Compare the various methods available for power factor correction from the point of view of initial cost and flexibility of operation.

(*b*) Estimate the leading kilo-volt amperes required to raise a 50 kilo-watt load from 88% Power Factor lagging to 95% Power Factor lagging.

6. Answer either (*a*) *or* (*b*).

(*a*) Indicate the chief constructional features of any form of electric furnace with which you are familiar.

(*b*) Estimate the length of time taken to raise 1,000 kilogrammes of metal to 900°C. from an initial temperature of 25°C., if the rating of the furnace is 100 kilo-watts and its efficiency 80%.

[Specific heat of metal=0.09].

One gramme Calorie=4.2 watt-seconds.

7. Answer either (*a*) *or* (*b*).

(*a*) Describe a portable petrol driven arc welding set of about 200 amperes output.

(*b*) Describe a semi-automatic nickel plating plant for cycle accessories.

8. Define the terms: Demand factor; diversity factor and load factor and state clearly their separate effects upon the cost of electrical energy.

WORKSHOP PRACTICE AND PROCESSES.

FRIDAY, 17TH APRIL, 1936. (2-30 P.M.—5-30 P.M.)

Examiner: J. LOXHAM, M.I.P.E., A.M.I.MECH.E.

Candidates are allowed to attempt FIVE questions only.

Maximum number of marks obtainable for each question is indicated in brackets.

1. Plan the sequence of operations and give brief details of the jigs and tools you would recommend for the production of one of the parts shown in Figures 1 or 2, in quantities of

(*a*) one only;

(*b*) 500 per batch. (28)

2. A shaping machine, a planing machine, a horizontal miller, a vertical miller, a surface grinder, a disc grinder, a slotting machine and a lathe are all used at various times for the production of flat surfaces. Give examples of the type of work to which any four of these machines is specially suited, and in addition, state the conditions necessary for accuracy in each case. (18)

3. The diameter of a certain part, say a pivot pin, is dimensioned as 1 in. $^{-.001}_{-.002}$ diameter. The bore of the bush into which this part is fitted is dimensioned as 1 in. $^{+.00075}_{-.0000}$ diameter.

(*a*) What type of a limit system has been used for the dimensioning of these parts?

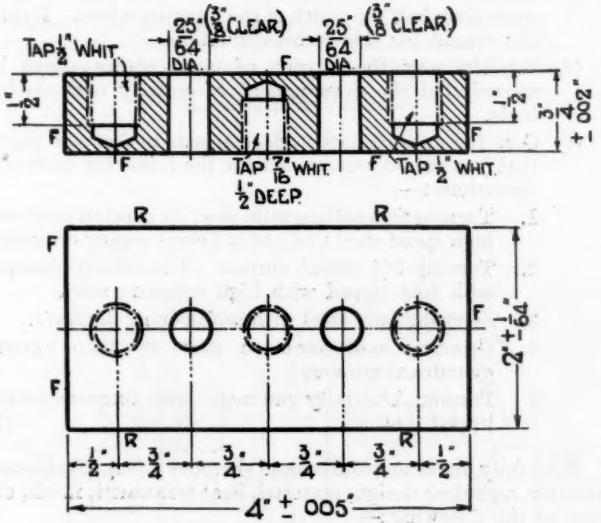
(*b*) Show by means of a diagram of fits, the above assembly, and indicate on the diagram the maximum and minimum allowance.

(*c*) Make a simple sketch of the type of gauges you would recommend for inspecting the above parts.

(*d*) How would you recommend that wear on gauges and unavoidable imperfections in the manufacture of gauges be dealt with? (Answer in about 70 words or by means of a diagram.) (18)

4. (*a*) Suggest any modification to the part shown in Fig. 3 which would facilitate manufacture.

(*b*) What system would you recommend to ensure that in all new designs, adequate attention is paid to methods of manufacture. (18)



F– FINISH MACHINE. R= ROUGH MACHINE.
MATERIAL CAST IRON

FIG. 3.

5. (*a*) What are the essential characteristics of an efficient cutting tool?

(*b*) To what extent are these characteristics possessed by tools made from plain carbon tool steel (cast steel); high speed steel; tungsten carbide tipped tools?

(*c*) Explain why different materials require tools having different angles of top rake. Give three examples, stating the approximate value of the angle in each case. (18)

6. Answer three of the following :—

(*a*) The feed box on some milling machines ensures a definite feed in inches per minute, while on others the table moves a definite amount per revolution of the machine spindle. What are the relative advantages of these two systems ?

(*b*) The speeds and feeds on the majority of machine tools are arranged in geometric progression. What is the reason for this arrangement ?

(*c*) For plain cylindrical grinding, it is frequently recommended that the traverse per revolution of the work be more than half the width of the grinding wheel. Explain the reason for this recommendation.

(*d*) Explain why the advent of new cutting alloys has necessitated the development of entirely new machine tools.

(*e*) Give the approximate surface speeds in feet per minute that you would recommend for the following machining operations :—

1. Turning free cutting mild steel on capstan lathe with high speed steel tool and a liberal supply of coolant.
2. Turning 3% nickel chrome oil hardened stamping with tool tipped with high tungsten steel.
3. Screwing mild steel with self-opening die head.
4. Grinding case hardened part on plain external cylindrical grinder.
5. Turning Admiralty gun metal with tungsten carbide tipped tool. (18)

7. Make fully dimensioned freehand sketches giving all necessary information regarding design, material, heat treatment, finish, etc., for one of the following :—

(*a*) Pair of 12 pitch spur gears to connect two parallel shafts $7\frac{1}{2}$ in. centre distance. Velocity ratio 2 : 1.

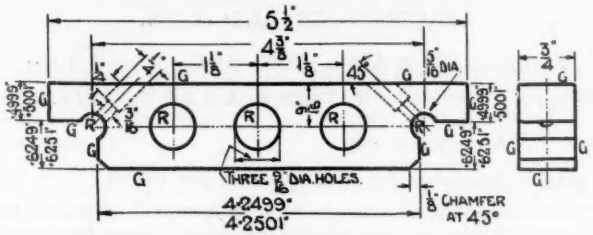
(*b*) One 6 in. diameter $\times \frac{3}{4}$ in. wide $\times 1\frac{1}{4}$ in. bore heavy duty, side and face milling cutter.

(*c*) Pair of toolmaker's " V " blocks with stirrup clamps. (18)

8. Give a definition of the following terms :—

(*a*) Normalising, Hardening, Tempering, Annealing, Higher Critical Temperature, Lower Carbon Change Point.

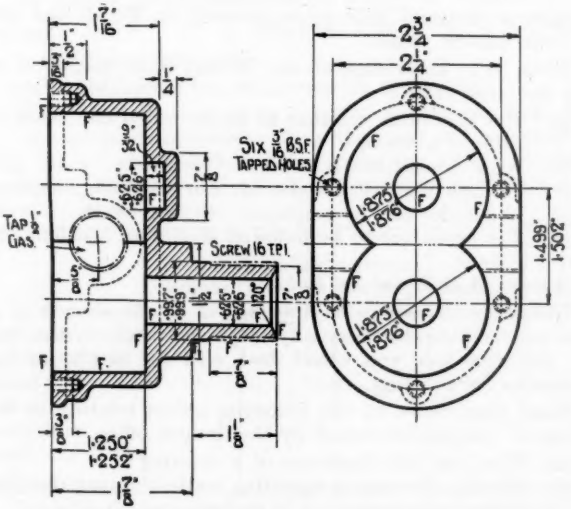
(*b*) Give examples of the effect of Carbon and of Nickel upon the physical properties of steel, and its behaviour when subjected to heat treatment. (18)



ROUGH MATERIAL, CARBON CASE HARDENING STEEL (SPEC. 2514) (1" x 1¼" BK. RLD.)
HEAT TREATMENT, CARBURISE FOR 4HRS, AT 900°C REHEAT TO 900°C & QUENCH.
R = ROUGH MACHINE G = GRIND. REHEAT TO 780°C & QUENCH.

5" SINE BAR. (BAR ONLY)

FIG. 1.



MATERIAL CAST IRON F = FINISH MACHINE

GEAR PUMP BODY.

FIG. 2.

FACTORY ORGANISATION.

SATURDAY, 18TH APRIL, 1936. (10-0 A.M.—1-0 P.M.)

Examiner: J. FRANCE, A.M.I.P.E., A.M.I. Mech.E.

Answer FIVE questions only.

The marks obtainable for each question are stated.

1. At the present time wages tend to increase, whereas interest rates on capital are low. Discuss the influence of these circumstances upon the policies adopted by companies wishing to increase production. (25)

2. Plan an electric lighting installation suitable for the workshop shown in Fig. 1. With reference to your plan state :—

(*a*) The heights of the lamps above the floor.
(*b*) The wattage of the various lamps.
(*c*) The types of fittings to be used. Give a sketch of each.
(*d*) The average light values (in foot candles) which you hope to obtain on the working plane.

Mark your proposed light points actually on Fig. 1, and attach it to your answer papers. (20)

3. From your knowledge of the Factory Acts relating to non-textile factories, state :—

(*a*) The maximum number of hours which can be worked without a break.
(*b*) What constitutes a break ?
(*c*) For how many hours per day can women be employed ?
(*d*) If females can be employed on night work.
(*e*) The procedure to be followed should an accident occur. (20)

4. *Answer A or B but not both.*

A. Necessary alterations to drawings of details already in production can be made either casually or systematically by the designs office. Describe how you would deal with the matter and give your reasons for so doing. (20)

B. State your views on the following points relating to detail drawings of components issued by the designs office.

(*a*) What are the functions of a drawing ?
(*b*) Should information regarding method of manufacture be given ?
(*c*) Should limits be stated ?
(*d*) If given, should limits be in figures or symbols ?
(*e*) Should surface finish be quoted ?
(*f*) Should quality of material be specified ? (20)

5. Name as many different sources of power as you are able. Discuss the applications of each and state their advantages and disadvantages. (15)

6. Outline the duties of the organisation lying between the drawing office and the works which you consider would ensure efficient production. Why do you consider your suggested organisation necessary? (15)

7. Two sites are available for the erection of a new factory. One is in the centre of a city and the other in the country a few miles outside the city. Set down the items of which you would take particular note if sent to examine the sites with a view to recommending which to purchase, and show how they would influence your decision. (15)

8. Do you consider that apprentice training schemes should endeavour to produce future craftsmen or future executives? Describe a scheme that meets your view and is yet economical. (15)

PLANNING, STOREKEEPING, AND COSTING.

SATURDAY, 18TH APRIL, 1936. (2-30 P.M.—5-30 P.M.)

Examiner: J. FRANCE, A.M.I.P.E., A.M.I.Mech.E.

Answer FIVE questions only.

The marks obtainable for each question are stated.

1. The following chart gives a list of metals, together with a list of market forms of metals. Copy the chart and complete it by writing "yes" under each heading where the metal is ordinarily obtainable in that form. If not, state "no" and add below a brief explanation of the reason. (25)

	Rolled sections	Extr'ded sections	Solid drawn tubing	Sand castings	Die castings
Mild steel ...					
High speed tool steel ...					
Cast iron ...					
Aluminium ...					
Brass					
Lead					

2. Describe the organisation of a progress department and show how it functions to maintain a scheduled production programme. (20)

3. Piece-workers must be able to earn more than day-rate workers. State:—

(*a*) How this is allowed for when setting times. Give an example.

(*b*) Whether the same allowance should be made with straight piecework as with a premium bonus scheme.

(*c*) In the light of your answer to (*b*) which of the two schemes is preferable, and why?

(*d*) Why do both schemes find a use? (20)

4. Take four different types of machine tools (one of them being a press) and suggest ways by which production from such machines might be increased and the necessity of purchasing additional plant obviated. (20)

5. *Answer A or B, but not both.*

A. With reference to a work's stores organisation, answer the following questions:—

(*a*) What are the functions of a stores?

(*b*) Should large or small stocks be carried? Give reasons.

(*c*) How can a strict watch be kept upon the accuracy of stores records?

In each case differentiate between production and tool stores. (15)

B. Outline a system whereby the indiscriminate issuing of small tools from stores can be avoided, and a check kept upon those responsible for excessive loss and damage. (15)

6. The following list of parts comprises a special machine. State the amount of material (or number of each) that you would buy to ensure 100 complete machines being assembled, and give your considered reasons for buying these quantities. (15)

Part No.	Quan. per set	NAME	Mat'l	REMARKS
1	1	Main casting	C.I	Intricate casting bought; machining simple.
2	20	Spindle	M.S.	Made from bar on auto lathe.
3	40	Bearing housing	C.I	Simple castings bought, close limit machining required.
4	40	Ball bearing	Steel	Standard design, bought finished.
5	20	Lever	M.S.	Drop forgings bought, machining intricate.
6	210	Hex. bolts	M.S.	$\frac{1}{2}$ in. dia. Whit. × 2 in. long, standard, bought finished.

7. The demand for the products of many works varies with the seasons. Explain how this affects the recovery of overhead charges, and how it is allowed for. (15)

8. Investigation shows that to make 5,000 components on an existing capstan lathe would take one hour each piece. If a new automatic lathe were purchased for £450 the parts could be produced in half an hour each. Combined wage and overhead costs are 3s. per hour.

State, giving reasons, whether you would, or would not, recommend the purchase of the new machine. (15)

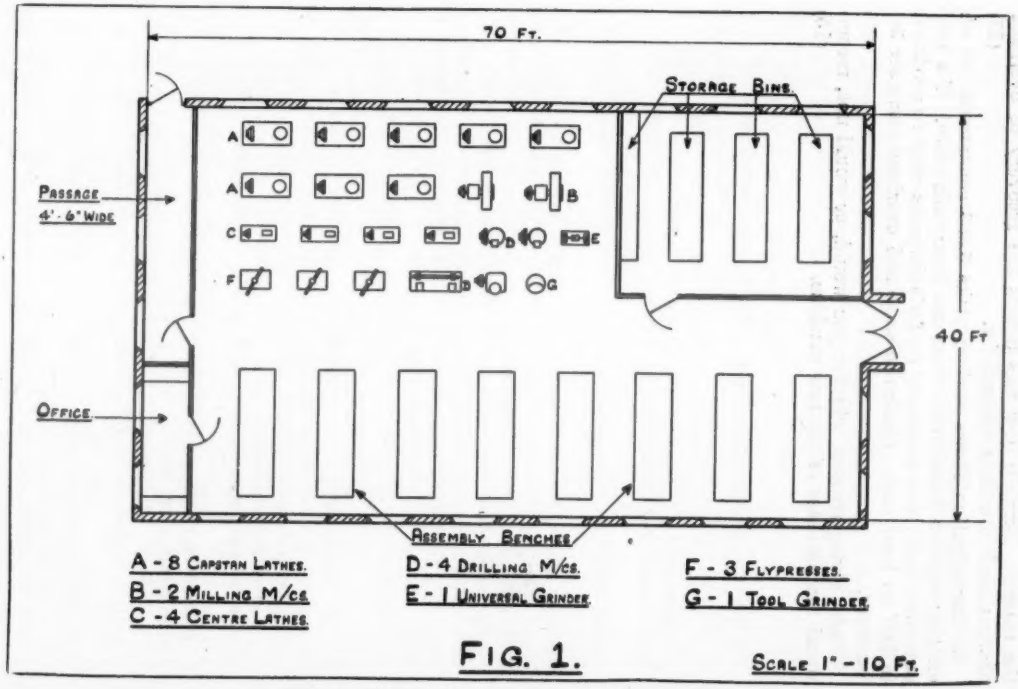


FIG. 1.—PAPER ON FACTORY ORGANISATION.

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